

# Improving Railroad Safety and Rail Passenger Technology through Targeted Research and Demonstrations 1992-1997

---



U.S. Department  
of Transportation  
**Federal Railroad  
Administration**



Office of Railroad Development  
Washington, DC 20590

---

August 1999  
DOT/FRA/ORD-99/02  
DOT-VNTSC-FRA-98-9

**NOTICE**

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

**NOTICE**

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

<b>REPORT DOCUMENTATION PAGE</b>			<i>Form Approved</i> OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE August 1999		3. REPORT TYPE & DATES COVERED Final Report January 1992 - December 1997
4. TITLE AND SUBTITLE Improving Railroad Safety and Rail Passenger Technology through Targeted Research and Demonstrations 1992 - 1997			5. FUNDING NUMBERS RR903/R9038 RR919/R9013 RR928/R9025 RR993/R9021 RR997/R9007	
6. AUTHOR(S) Federal Railroad Administration, Office of Railroad Development Staff				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of Transportation      Volpe National Transportation Systems Center Federal Railroad Administration      55 Broadway Office of Research and Development      Cambridge, Massachusetts 02142 1120 Vermont Avenue, NW Mail Stop 20 Washington, D.C. 20590			8. PERFORMING ORGANIZATION DOT-VNTSC-FRA-98-9	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSORING/MONITORING DOT/FRA/ORD-99/02	
11. SUPPLEMENTARY NOTES This report summarizes research and development carried out by the Federal Railroad Administration's Office of Railroad Development and supporting organizations. The report was prepared by the Department of Transportation, Research and Special Programs Administration, at the John A. Volpe National Transportation Systems Center, Cambridge, Massachusetts, a supporting organization.				
12a. DISTRIBUTION/AVAILABILITY This document is available to the public through the National Technical Information Service, Springfield VA 22161. This document is also available on the FRA web site at <a href="http://www.fra.dot.gov">www.fra.dot.gov</a> .			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The Office of Railroad Development of the Federal Railroad Administration conducts research, development, test, and evaluation projects to directly support the Federal Railroad Administration's safetyresponsibility and to enhance the railroad system as a significant national transportation resource. This report summarizes the Office of Railroad Development activities from 1992 - 1997. A report published in 1992 covered the years 1988 - 1991. This report does not include all the Office of Railroad Development activities undertaken; instead, it is representative of the work performed. Many projects were undertaken in conjunction with the railroad industry. Where required by the Federal Railroad Administration's public safetyresponsibility, the work was performed independently. The Office of Railroad Development has relied on cooperative and coordinated programs with other research organizations, other Government agencies, industry associations, individual railroads, and industry suppliers. Organizations participating in cooperative research include the Association of American Railroads; Railway Progress Institute; American Railway Engineering and Maintenance-of-Way Association; Brotherhood of Locomotive Engineers; United Transportation Union; individual U.S. railroads and their suppliers; and the Canadian Government and railroads.				
14. SUBJECT TERMS Transportation, safety, research and development, equipment and components, system operations, environment, intelligent track/train systems, track systems, locomotives, rolling stock, highway-rail grade crossing, next generation high-speed rail, high-speed rail safety assurance, railroad.			15. NUMBER OF PAGES 165	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	



# INTRODUCTION

The first priority of the Federal Railroad Administration (FRA) is the safety of the United States railroad system, which, in 1996, included 173,000 route miles of track, 19,270 locomotives, 6,500 passenger cars, 1,240,000 freight cars, and 205,000 employees. The demands on this system are continuously growing, and changing technologies provide the opportunity to improve system effectiveness and efficiency. The FRA addresses safety concerns in all phases of railroad operations, through research and development, regulatory, and enforcement activities to ensure that railroads in the United States continue to be among the world's safest.



Photograph courtesy of Bombardier, Inc. Transportation Equipment Group



FRA Office of Railroad Development projects contribute vital inputs to the FRA's safety regulatory processes, to railroad suppliers, to railroads involved in the transportation of freight, intercity passengers and commuters, to railroad employees and their labor organizations, and to states and municipalities. FRA-owned facilities

provide the infrastructure necessary to conduct experiments, test theories, concepts, and other technologies in support of the research and development program. Every attempt is made in research and development planning to anticipate and prevent potential safety threats. The emphasis is on producing technically and economically sound countermeasures to ensure the continued and enhanced safety and efficiency of railroad transportation.

In supporting the safety mission of the agency, FRA's Office of Railroad Development looks toward rail transportation for the 21st Century. Issues include ensuring that the safety implications of the following industry trends are known:

- changing tank car design
- faster and heavier rail cars
- new passenger and crew space designs
- increasing passenger train speeds
- increasing mixed passenger/freight operations
- new braking systems for both passenger and freight train consists
- improved rolling stock on-board and wayside detection systems
- more complex equipment and systems

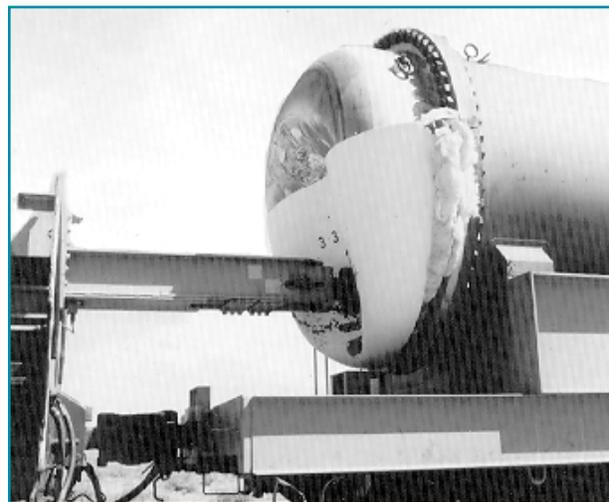


The FRA, in an effort to ensure maximum leveraging of research funds and to eliminate duplication, cooperates extensively with the Association of American Railroads (AAR), the Railway Progress Institute (RPI), American Public Transit Association (APTA), the National Railroad Passenger Corporation (Amtrak), the Transportation Research Board (TRB), and government agencies such as the Federal Transit Administration (FTA), the Federal Aviation Administration (FAA), and the National Transportation Safety Board (NTSB). Cooperation with the AAR occurs primarily in the areas of track/train interaction, track safety research, bearing defect detection, braking systems, grade crossings, train control, and hazardous materials (hazmat) transportation. The FRA has a contract with the AAR under which its wholly owned subsidiary, Transportation Technology Center, Inc. (TTCI), manages FRA's Transportation Technology Center (TTC) at Pueblo, Colorado. The RPI arranges for its supplier-members to provide material and equipment for the Facility for Accelerated Service Testing (FAST) at the TTC, and also participates in the hazmat transportation projects. APTA, Amtrak, FTA, FAA, and the NTSB cooperate with the FRA on projects aimed at improving protection for railroad

passengers. Representatives from the FRA serve on a number of TRB and industry committees to ensure that duplication of effort is avoided.

Human factors testing and simulations are carried out at FRA's other major facility: the Research and Locomotive Evaluator/Simulator (RALES) facility managed and operated by the Illinois Institute of Technology Research Institute (IITRI) in Chicago, Illinois for the FRA. RALES consists of a computer controlled, motion-based locomotive cab which is capable of training locomotive engineers and conducting research projects.

Over the last 5 years, FRA Research and Development has concentrated on applying research results from previous years to foster improved maintenance inspections and detection methods and techniques. FRA research supports the introduction of systems and devices that prevent track, equipment, or human failures which may cause derailments or collisions. The FRA's cooperative programs with industry reflect that approach. With a goal of complete elimination of



accidents, FRA research is also oriented toward ensuring that employees, passengers, and persons close to hazardous materials carried in trains are protected to the maximum extent possible – even in the event of an accident.

FRA research also supports safety rulemaking initiatives which are designed to ensure that the safety of new technologies and high-speed



passenger systems is maintained. During the period covered by this report, significant research results were achieved, through industry and academic outreach, in areas of automated systems safety validation and verification, collision avoidance and accident survivability, emergency preparedness, and right-of-way security.

During this reporting period, the FRA also undertook a new initiative, the Next Generation High-Speed Rail Program, as part of the Swift Rail Development Act of 1994. This program focuses on bringing innovative new technology to high-speed passenger rail industry. Key areas of research which will help enable higher speed operations are propulsion technologies, advanced control systems, and innovative grade crossing safety enhancements.

This report is organized into two major areas:

- Improving Safety
- Technology Advancement

**Improving Safety** consists of the following:

- Human Factors
- Rolling Stock
- Track and Structures
- Vehicle/Track Interaction
- Intelligent Track/Train Systems
- Highway-Rail Grade Crossing Safety
- Hazardous Material
- Train Occupant Safety
- High-Speed Rail Safety Assurance
- Research and Development Facilities and Test Equipment

**Technology Advancement** consists of the following:

- Next Generation High-speed Rail
- Track Evaluation, Improvement, and Maintenance
- Signaling and Communication Improvements
- Grade Crossing Risk Mitigation
- Non-Electric Locomotives
- Lightweight Brake Materials

For information on FRA Research and Development results prior to 1992, please reference *Improving Transportation Through Railroad Research, 1988-1991*, DOT/FRA/ORD-92/14, July 1992.



# HUMAN FACTORS





# TRAIN, YARD, AND TERMINAL OPERATIONS

## SUMMARY

Since 1985, human factors accidents have accounted for approximately one third of all railroad accidents. In 1995, of 2,619 total reported accidents, those attributed to human factors amounted to 944. One key to preventing accidents involving locomotive crews is to understand the abilities and limitations of the operator and how he or she interacts with the system. Over the last 5 years, the FRA has been engaged in several areas of research examining how various aspects of railroad operations affect the operator and ways to address consequential safety considerations. Human factors embraces a wide variety of problems that can contribute to accidents, including:

- fatigue, sleep disruption, and stress;
- communication and information-display systems that either omit critical safety data or present it in such fashion that it can be misinterpreted;
- operating rules and practices that are potentially confusing; and
- environmental factors in the locomotive cab that adversely affect employee health and aggravate the aforementioned problems.

Development of cost-effective strategies to reduce human error requires quantitative measures of the factors that contribute to these accidents and quantitative evaluation of proposed improvements. The FRA, working closely with the Volpe Center, Foster-Miller, Inc., the Massachusetts Institute of Technology, and the Illinois Institute of Technology Research Institute (IITRI), develops, analyzes, and evaluates these issues.

## RESEARCH STATUS

The following reports were completed during the last 5 years.

*Locomotive Engineer's Activity Diary.* About 200 freight engineers working on several major railroads completed a 14-day diary recording such data

as demographic characteristics of the participants; how much time they spent working, sleeping at home, sleeping away from home, commuting and all other activities. Data were also gathered regarding their quality of rest, how alert they felt on the job at various times of day, and how well they could predict the time of their next job start. These data were analyzed to show relations among various factors, such as, alertness by time of day, sleep hours by place of rest, and hours worked by type of work performed.

*Compliance with Railroad Operating Rules and Corporate Culture Influences: Results of a Focus Group and Structured Interviews.* A focus group, supplemented with structured interviews, was convened with railroad operating rules officers from Class I, II, and III railroads to evaluate compliance with railroad operating rules. The report categorizes the major operating rule compliance problems (as perceived by operating rule managers), and discusses some of the major roadblocks to rule compliance, particularly regarding how organizational culture might be encouraging operating rule violations indirectly.

*Safety of High Speed Guided Ground Transportation Systems – Human Factors, Phase I: Function Analyses and Theoretical Considerations and Phase II: Design and Evaluation of Decision Aids for Control of High-Speed Trains: Experiments and Model.* The first of these reports focuses on the safety implications of the disparity between rising operating speeds and the essentially fixed reaction and information-processing times of human operators. It discusses human-factors aspects of the French, German, and Japanese high-speed systems and reviews salient literature. It also addresses the human-machine allocation of control authority and the safety implications of various levels of automation.

The second report describes the design and evaluation of computer-based decision aids to compensate for the increased demands placed upon engineers

by high-speed operations. Three concepts of aiding, referred to as preview, predictive, and advisory aiding, were integrated into two displays in the Volpe Center Train Simulator and compared with a conventional high-speed cab. Experimental results show that decision aids improved safety by both reducing reaction times to emergency events and the need for emergency brake applications. Schedule adherence, station-stopping accuracy, and, with advisory aiding, fuel consumption also improved.

Additional reports in this series are in preparation. FRA staff also provide consultation and advice to railroads on fatigue-related issues. This allows FRA staff to monitor ongoing industry efforts and keep apprised of them.

## KEY FINDINGS

- Although fatigue and stress are complex, multi-causal problems, they can be effectively addressed through well-designed programs of countermeasures. On-going countermeasure projects are demonstrating the efficacy of a combination of more predictable schedules, on-the-job rest at appropriate times, better sleeping facilities and lifestyle training. These measures not only improve health and safety, but also save money for railroads in terms of numbers of employees required to staff a pool as well as hotel and deadheading costs. Among proposed measures to combat fatigue, engineers favor improvements in work schedule predictability over all others by a wide margin.
- Compliance with railroad operating rules: Although rules managers and line supervisors generally enforce compliance with operating rule violations, senior management may unintentionally encourage overlooking operating rule violations with pressures for improved productivity.
- Advanced cab information displays can enhance both safety and economics.

## STUDIES IN PROGRESS

*Shorter-than-24-hour Work/Rest Cycles in the Railroad Industry* – Dr. June Pilcher of Bradley University is re-analyzing data from the Locomotive Engineer’s Activity Diary project. This

study addresses four issues concerning the work/rest schedules of engineers: (1) the frequency of work/rest cycles shorter than 24 hours; (2) whether or not the frequency of such cycles varies the type of work performed; (3) whether or not such short cycles have detrimental effects on sleep quantity, sleep quality, and self-rated alertness; and (4) whether or not type of work affects sleep quantity and quality or alertness ratings.

*Railroad Worker Safety in Yards and Terminals* – Safety in the railroad industry has improved dramatically over the past 20 years, yet the annual cost of railroad worker injuries exceeds \$1 billion. A preliminary study conducted by Foster-Miller Inc. (FMI), Human Factors Issues in Railroad Yard and Terminal Safety, found that, based on 1994 data, certain yard job categories experience significantly higher injury rates than the industry average for all railroad and all yard workers. Frequency of accidents also appears to be related to time of day. The Phase I Study concluded that the FRA’s accident/incident data base is useful for determining overall trends but provides limited data for determining the root cause of injuries. The Phase II Study, currently underway, will analyze multiple years of accident and injury data to confirm the findings of the earlier work. In addition, qualitative research methods will be used to complement the analysis of existing data sources and a design for new data collection will be developed.

A committee of experts from the railroad industry and FRA has been formed to determine the causes of fatalities in switching operations. The SOFA (Switching Operations Fatalities Analysis) group, focuses solely on fatalities and uses subject matter expert opinion to analyze each fatality. The Volpe Center supports this effort through the conduct of statistical and cognitive-task analyses as well as the development of recommendations to the industry.

*Training Requirements for Railroad Dispatchers: Objectives, Syllabi, and Test Designs* - In an effort to increase the uniformity, quality, and efficiency of training train dispatchers, the FRA contracted with FMI for research to develop training objectives, model syllabi, and test designs. The approach involved two processes: gathering information about current methods and training programs, and applying an instructional design methodology to

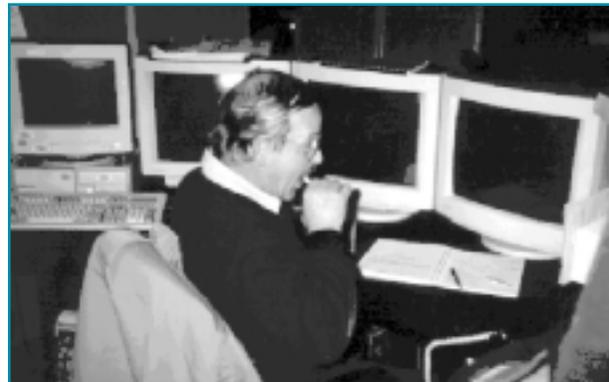
design of the objectives, syllabi, and test designs. Training objectives were conceived and organized around basic prerequisites and four dispatcher job functions: planning, controlling track use, managing unplanned and emergency events, and record keeping and report writing. A set of objectives was then selected for each of three types of training: initial dispatcher training, initial territory training, and periodic refresher training. Model syllabi and test designs were developed for each. Factors that appeared to contribute to successful training programs were identified, based on site visits and discussions with railroad training officials. The FRA sponsored a workshop in October 1998, to share the results of this work with the railroad industry and to provide a forum for industry training officials to share their experiences and concerns for the future. Elimination of most traditional training positions, such as control tower operators, has created a need for a formal documentation of training selection requirements for new-hires for dispatching jobs.



Train Dispatcher at Console

*Railroad Dispatcher Workload, Stress and Fatigue* – The purpose of this FMI study is first to identify and understand the sources of dispatcher workload, stress, and fatigue, and then to propose interventions, both organization-based and employee-centered, to control the effects. A pilot test at two dispatching centers validated the feasibility of various measures for data collection in the dispatchers' workplace. A background survey was designed to obtain demographic data, describe any health problems, and identify workplace sources of stress. Based on the experiences of the pilot test,

sleep/wake cycles of the dispatcher participants will be monitored around the clock by means of actigraphy (wrist-worn monitors of physical activity). Samples of cortisol, a chemical found in saliva, will provide a measure of stress levels. Participants will provide a subjective assessment of workload. Data collected by an observer using a modified Task/Analysis Workload approach will provide an objective measure of workload. A field test, consisting of 2 weeks of data collection at a passenger railroad and 2 weeks at a freight railroad, occurred in August and September, 1998. Issues explored included differences among shifts, traffic volume effects, and time of day effects on the level of dispatcher workload, stress, and fatigue.



Participants provided saliva samples five times per day. The cortisol concentration in saliva is correlated with stress levels.

#### FUTURE RESEARCH

Fatigue countermeasures programs are now being planned or implemented by the FRA, Office of Safety, and various railroads. The Office of Railroad Development will provide technical support and advice to these efforts and assist in the evaluation of the effectiveness of various approaches.

One element of the fatigue countermeasures program, napping on duty, is particularly suited to evaluation in a simulator. The FRA has awarded a contract to IITRI to gather RALES-performance data from 48 engineers, each of whom will operate the simulator for approximately 50 hours over five nights in succession. The data will be analyzed by the FRA Office of Railroad Development and Volpe Center staff to determine how naps of various lengths during scheduled stops affect performance.



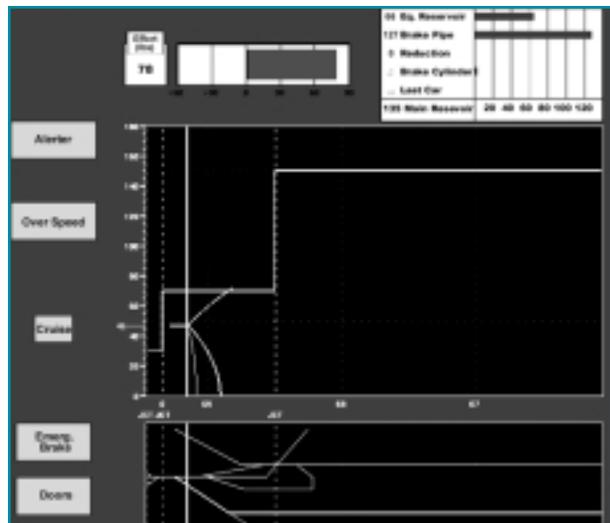
The RALES simulator at IITRI is being used to study the effects of on-duty rest on the performance of freight engineers.

At the Volpe Center Train Simulator, experiments are planned to elucidate the effects of technology on engineers and dispatchers, whose decision-making and collaboration processes are poorly understood. As railroads prepare to introduce new digital-communication and information-management technologies such as data link, to aid dispatchers and train crews, there is a lack of understanding about how this new technology will affect the decision-making processes, what information is required, and how this information should be displayed. If control technology is introduced, the role of the dispatcher needs to be determined, as well as the possibility of his or her intervention, if the technology fails. A cognitive task analysis will be conducted to learn what decisions dispatchers make and the inputs and outputs to these decisions. Output from this task will feed the evaluation of data link in railroad operations. Identification of information required by dispatchers, the decisions they make, and how they use information is needed to understand how data link might affect the safety and productivity of train operations.

A number of devices are under development to provide real-time monitoring and warning to operating employees with regard to their levels of alertness or vigilance. While these development efforts are being funded by other elements of the USDOT and private industry, the FRA plans to evaluate these devices for possible application in railroad operations in conjunction with simulator-based fatigue



Hundreds of sleeper seats are being installed in freight locomotives each year, beginning in 1998 to facilitate approved on-duty rest.



Predictive Cab Display in Volpe Center Train Simulators Shows Speed and Distance Traveled for Normal Acceleration, Service, and Emergency-Braking Conditions

experiments. It will also provide technical assistance to railroads that wish to conduct field trials of such devices.

# KNOWLEDGE DISPLAY INTERFACES

## SUMMARY

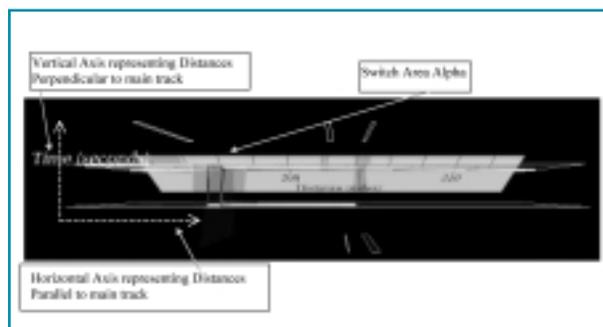
In future rail operations, real time data and computer links among locomotive engineers, dispatchers, and traffic managers will be standard. The display of information to facilitate comprehension and use of information under these circumstances will be essential if the improvement to safe system operation is to be realized. Innovations in train control can be expected to safely increase traffic density and speed on existing track, if information is shared between decision-makers and operators.

## RESEARCH STATUS

This joint project with Amtrak and the MIT Media Laboratory will provide concepts for innovative digital display environments to enable exploration, analysis, and testing of strategies to strengthen and coordinate safe decision-making when new high-speed operations begin on the Northeast Corridor.

## KEY FINDINGS

Dispatcher and Chief dispatcher functions are the areas that could most benefit from the advanced information display for strategic traffic management. These display concepts should better integrate and represent the variety of critical information structures the dispatcher teams typically rely upon for accurate comprehension and timely response to safety-critical operating situations. The Train Follower window concept is a new decision aid that may improve dispatch tracking of

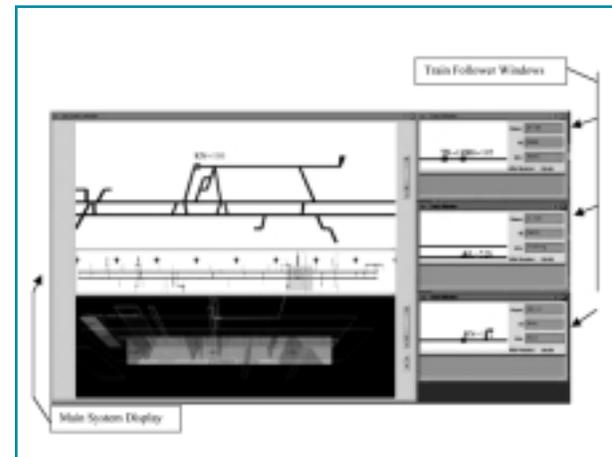


Three Dimensional String Diagram - Operating Schedule and Emerging Events

multiple trains and crew conditions. Another innovative concept is the 3-D string diagram. String diagrams are used to plan and schedule meets and passes. With the 3-D string, multiple track strategies can be rapidly developed and evaluated. There are promising interactive interface concepts which may be feasible in the future for displaying tools and techniques.

## FUTURE RESEARCH

This project will continue investigating display concepts that integrate and represent the variety of critical information structures that could improve accurate comprehension, timely response, and improved safety of the dispatch function for complex railroad operations. In addition, work will begin on a systematic documentation of the complex cognitive tasks and functions performed in the dispatching and traffic management settings.



Train Follower Window Concept Depicted on Right Integrated with Dispatch View on Left and Amtrak Shoreline Overview on Bottom

## LOCOMOTIVE CAB WORKING ENVIRONMENT

---

The Rail Safety Enforcement and Review Act (RSERA) mandated that the Secretary of Transportation determine the need for regulatory action on locomotive cab working conditions. The mandate followed frequent expressions of concern by employee organizations, congressional members and recommendations of the National Transportation Safety Board.

### RESEARCH STATUS

**Human Factors Guidelines for the Evaluation of the Locomotive Cab** - This report presents human factors guidelines for the evaluation of the locomotive cab. These guidelines are part of an effort to evaluate working conditions and safety in the locomotive cab and will serve as a decision-making tool for evaluating current and proposed locomotive designs. Chapters within the guidelines address the following topics: heating, ventilation, air conditioning, noise, vibration, toilet facilities, general considerations for cab layout, ingress and egress, visibility, seating and workstation design. Within each section, human factors considerations were presented within the context of relevant operational issues and specific recommendations were offered.

### KEY FINDINGS

**Locomotive Cab Noise** - The noise level in many locomotives is sufficiently high to interfere with normal voice communications. A significant number of locomotives exhibit noise levels high enough to contribute to long-term hearing loss in the absence of personal protection equipment and after long-term repetitive exposure. A noise-level goal of 80 dBA is desirable to minimize hearing impairment. For minimal interference with speech communications, further reduction to 75 dBA is suggested.

**Cab Temperature** - There is considerable evidence that environmental conditions related to climate control affect stress levels and job performance. Conditions outside of perceived comfort zones can

contribute to stress and reduce performance. Inadequate heat in the locomotive cab can lead to increased fatigue due to shivering and reduce reaction times needed to control the train. Exposure to excessive heat contributes to fatigue. In cold environments, the locomotive cab should be maintained at a temperature between 64° F - 68° F, with the relative humidity between 30 and 70 percent. In hot environments, the locomotive should be cooled to a temperature between 72° F - 78° F, with the relative humidity between 30 and 70 percent.

**Sanitary Facilities** - Provision of adequate sanitary facilities is a controversial and difficult problem. Sanitary facilities are frequently designed to fit the space available rather than to meet the needs of the cab crew. Lighting and climate controls are inadequate and odor is a significant problem. The extremes of temperature that the locomotive experiences makes waste disposal a challenge. Maintenance is also a problem due to servicing requirements and the shared nature of these facilities. Two light levels are recommended, one for day and one for night. Adequate ventilation is necessary to remove odors when present and to facilitate climate control. Sanitary facilities should be designed of materials to facilitate cleaning. Adequate barriers are needed to prevent odors from the waste storage area from leaking into the lavatory.

### FUTURE RESEARCH

The Office of Railroad Development is supporting the Office of Safety in gathering data describing the performance of heating and cooling systems on a sample of about one hundred locomotives in revenue service. These data will be used to assess the need for regulatory changes.

Moreover, a review of the relationship between temperature and human performance is being conducted for ORD by the Volpe Center to the safety implications of temperature extremes.

# ROLLING STOCK





# EQUIPMENT AND COMPONENTS

## SUMMARY

This section deals with research activities related to the safety related performance of locomotives and railroad cars and the components and appurtenances necessary for their proper functioning, such as wheels, bearings, and brakes. The research activities include analyses, tests, evaluations, and demonstrations. Current research is expanding on that previously performed in developing and maintaining freight car standards, wheels, brakes and bearings.

The structural integrity and dynamic performance of railroad equipment and components is vital to the safety of railroad operations. Research in this area will continue to play a valuable role in developing new or revising existing regulations to continue to preserve the safety of railroad operations. Details of the targets of future research are identified below.

## Advanced Braking

Technological developments make it possible to improve the braking performance of railroad cars through the use of electronic controls to activate the braking systems used in freight service. The FRA is participating in research to evaluate the feasibility and safety of proposed advanced braking systems.

## RESEARCH STATUS

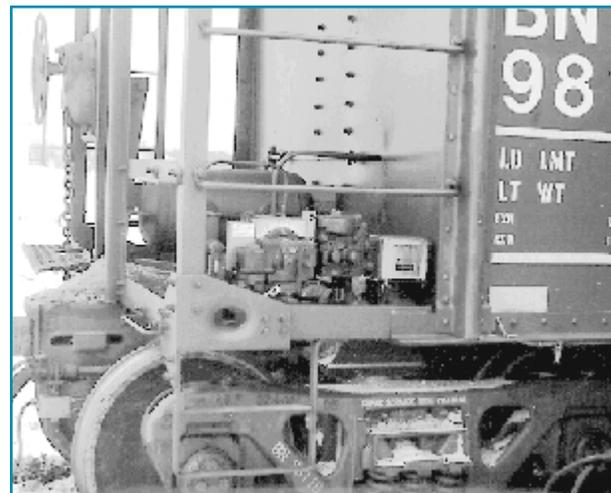
In order to overcome the limitations of conventional air brake systems, the AAR has been working on an advanced brake system study to improve the safety, performance and reliability of the braking systems used in North American freight railroad service. The ultimate goal is to develop an AAR performance specification for advanced freight brake systems used in an interchange service.

In 1995, the FRA formed a partnership with the AAR to help fund research conducted under the Electronically Controlled Pneumatic (ECP) brake program. The current draft performance requirements call for a system with the following features:

- brake pipe is used to supply air only;
- electronic control of brake cylinder pressure using a wired train line;
- graduated release;
- health monitoring of the brake system; and
- time in the signal protocol for vehicle health monitoring and distributed power.

In 1996, several tests of ECP wire line brake equipment were completed:

- fifty-car sets of ECP brake equipment were tested on the 150-car test track;
- ECP equipment was installed and tested on Conrail unit coal cars;
- ECP-equipped BNSF double stack trains completed more than 150,000 miles of service; and
- the train used in the facility for accelerated testing (FAST) at TTC was equipped with ECP brakes.



ECP Equipment on FAST Hopper

## KEY FINDINGS

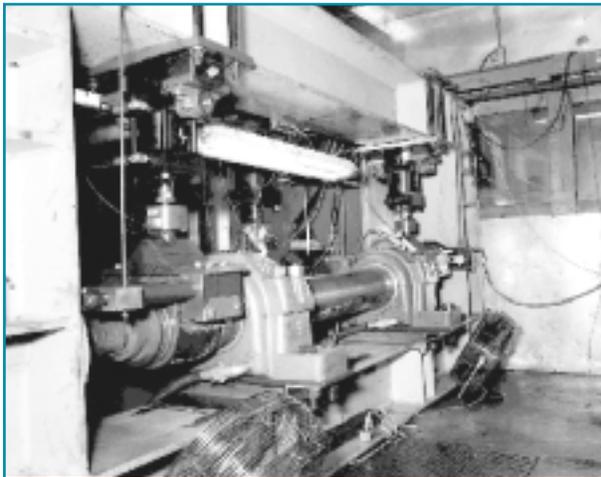
Preliminary findings indicate that ECP-equipped trains show significantly lower numbers of wheel change-outs due to brake-related defects, along with a higher consumption of brake shoes, indicating higher crew use and acceptance of the system.

## FUTURE RESEARCH

Provisions for testing and evaluation of alternate approaches to ECP braking concepts, such as radio-based wireless systems, will be available. Interoperability testing to verify that candidate systems comply with the ECP specifications is currently being conducted. The FRA will continue to monitor and assist the development and deployment of novel braking system technologies.

## Improved Roller Bearing Wayside Train Inspection Research

The FRA and the AAR joined forces to advance a program aimed at improving the ability of railroads to inspect roller bearings. Current infrared detection technology has proven to be inadequate as demonstrated in bearing burn-off statistics and the rate of false detection train stoppages. An improved detection system would have the ability to detect bearing failures and the type of defect at an earlier stage in the failure process.



Roller Bearing Test Rig

## RESEARCH STATUS

This joint program has elicited broad industry support. Many universities, national labs, and railroad suppliers are participating in the program and are using the test data generated to develop new detection technologies and algorithms.

The program consisted of two phases, funded by the FRA and performed by the AAR. Phase I was an extensive laboratory test that generated defective

and good bearing vibration and acoustic signatures used for algorithm development. Phase II consisted of a simulated revenue service test at the TTC, where acoustic data were recorded from defective and good bearings mounted on empty and loaded freight cars run past wayside microphones. The Phase II tests also encouraged potential developers to collect their own data, and several did so. The testing was successfully completed near the end of 1996. The data generated from the Phase I testing has been distributed to all participants; data from Phase II is still being reviewed. With this data, it is expected that a better detection technology could be implemented on the North American railroads in the near future, resulting in reduced operating costs and improved safety.

## KEY FINDINGS

One of the major milestones of this research effort is the determination that defective bearings can be identified by their acoustic signatures. The neural network technique has been applied to distinguish the type of defect based on this signature. The wayside acoustic program demonstrated that advanced processing techniques, such as neural networks, are critical to the ability to accurately detect and classify defects. Defect recognition is influenced by the speed of the passing vehicle and the load on the bearing.

## FUTURE RESEARCH

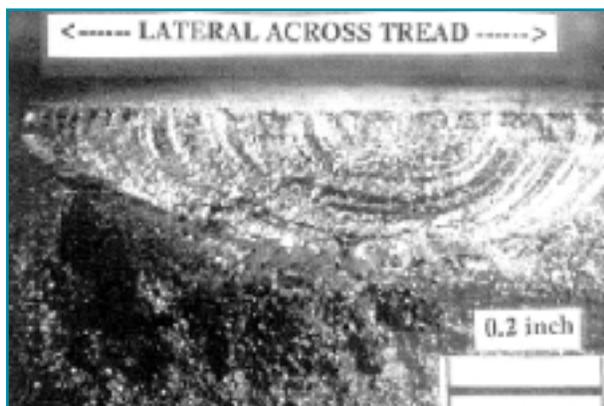
Current work is geared toward development of data to support FRA regulations permitting reinstallation of used (secondhand) bearings. Further testing will be accomplished to better educate the neural network developed by the AAR. A test plan is being developed for Phase III testing, in which participants in the research program will be given the opportunity to exercise their systems in the presence of an actual train. Testing at the TTC should begin around mid-1998 during which the prototype systems will be exposed to an operating train with various types of bearing defects.

# RAILROAD WHEEL PERFORMANCE

The structural integrity of railcar wheels is vital to the safety of the traveling public. The FRA embarked upon a research program to investigate safe performance limits for wheels when, in the fall of 1991, widespread cracking was observed by FRA inspectors on several New York area commuter railroads. The FRA research program began as a preliminary investigation to determine the cause(s) of the cracking epidemic and to develop countermeasures which could be put in place quickly in order to maintain safe operations without major impact on the large number of commuters who rely on the service.

## RESEARCH STATUS

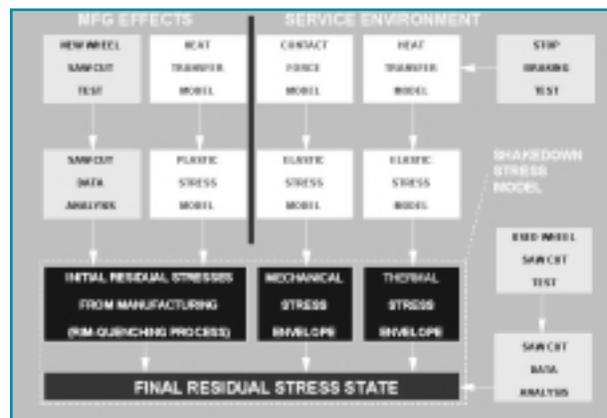
The study revealed that excessive tread braking caused overheating and cracking of the wheel rim. A secondary cause was identified as concentrated wheel rim heating resulting from misaligned brake shoes which overhung the wheel rim following improper brake system maintenance. The formation of the cracks is a result of rapid heating of a shallow layer of the wheel rim. This region expands due to



the thermal effects and becomes stressed beyond the strength of the material. The accompanying photographs illustrate the observed thermal cracking which is distributed more or less uniformly around the wheel circumference. A remedial action plan was developed which permitted the affected railroads to continue operations safely.



Following the initial investigations, the FRA, with the support of the Volpe Center, developed a master plan for the assessment of commuter rail car wheels. Residual stresses, those stresses which are “locked” in a body when external loads are



removed, are a well-known cause of premature failure of structural components. The ultimate goal of the research program is to develop a method of analysis which can be pro-actively applied to estimate how service demands placed on wheels can lead to adverse residual stress in the outer rim. A schematic representation of the research plan appears above, in which the shaded portions of the program represent laboratory and field testing which was done to corroborate the analytical model development.

**Stress Analysis** - Safe performance limits for wheels were established as one of the targets of the research. To capture the effects of service variables on the stresses developed in railroad wheels, all contributing factors must be included:

- stresses from manufacturing processes,
- stresses developed from wheel on rail contact, and
- thermal load stresses caused by friction between the brake shoe and wheel during braking.

A product of this research has been the development of tools which represent the state-of-the-art in residual stress analysis. The software used for the wheel studies was developed by the Francis Bitter National Magnet Laboratory at the Massachusetts Institute of Technology. The software includes the ability to account for the effects of residual stresses arising from all contributors and provides a prediction of the final residual stress state in the wheel rim after multiple applications of service loads. This is the so-called “shake down state” - the point at which residual stress fluctuations have stabilized and a “semi-permanent” state of stress has been developed in the rim.

#### KEY FINDINGS

The manufacturing process by which railroad wheels are made involves a final heat treatment and water spray quench to induce beneficial compres-

sive residual stresses in the rim to close, and retard further growth of, small cracks which may initiate on the tread surface. However, when wheels are placed in service and subjected to the repeated mechanical loads from wheel-on-rail contact and the thermal cycling of on-tread braking, the potential exists for high tensile stresses to develop in the material near the tread surface. These high tensile stresses may negate the residual hoop compression and result in net rim tension, a phenomenon referred to as “rim stress reversal.” In this case, small cracks which form in the wheel tread will be exposed to a tensile stress field which may cause accelerated growth and could result in catastrophic wheel failure.

#### FUTURE RESEARCH

These effects are the subject of current FRA research aimed at the assessment of the degree of rim stress reversal as a factor in safe operating limits for wheels in commuter operation. The current goal of the program involves application of the analytical tools to estimate shake down residual stress states in wheels on electric multiple-unit trains subject to service conditions which approximate the environment on properties in the New York area, including Metro North, New Jersey Transit, and the Long Island Rail Road. The model predictions of rim residual stress will be compared with observed service defect rates (the number of wheels found to be thermally cracked).

# TRAIN MAKE-UP

---

Studies of the relationship between train makeup and derailment safety are being conducted. It is expected that the FRA, Office of Safety will apply the results of these studies to determine the adequacy of current practice, the need for improved guidelines, and requirements for regulatory actions.

## RESEARCH STATUS

Research in this area is in its developing stages. The goal of the effort is to develop data related to in-train placement of freight cars, and to determine how such placement influences derailment potential. Much work has been done by the AAR on this topic, and has been documented in a set of guidelines for good practice.

Current research seeks, as a primary goal, to investigate whether available knowledge and/or guidelines are adequate and realistic for railroad operations.

## KEY FINDINGS

To date, results of this research have been limited to providing technical data to the FRA Office of

Safety. Data have been collected from railroad terminals across the country that describe the train make-up of actual trains leaving major terminals. Assessment of this data is underway.

## FUTURE RESEARCH

Research in this area will consist of several individual activities.

- Identify and accumulate relevant guidance material and results of previous studies related to “good practice” for train makeup and train handling. A preliminary collection of potential sources has been identified.
- Review reports of accident investigations where the cause has been identified as improper train makeup.
- Determine the relationships between actual train makeup in current railroad operations and the recommended guidelines.
- Compare current practice with the body of train makeup guidance.



# TRACK AND STRUCTURES





# TRACK SYSTEMS

## SUMMARY

Increased competition in the transportation industry has necessitated innovative changes in the design and maintenance of track, structures, signals and train control systems. The long-term effects of these changes on public safety must be determined by the FRA and considered in the conduct of railroad safety programs.

Safety standards for track and structures must be adapted to the state of the art to permit innovation while at the same time protecting the safety of the public.

Although the rate of train accidents on U.S. railroads has decreased over the past 20 years, track related accidents still constitute the major portion of the total, averaging over 1,000 accidents a year. Improvements in physical and economic factors in the railroad industry have led to higher train speeds, heavier cars and increased traffic density. Train accidents now have potentially more severe consequences than ever before.

The FRA continues to conduct research to reduce accidents attributable to failures of track, roadbed and structures.

This research directly supports the DOT's "Statement of National Transportation Policy", particularly in ensuring that the rail transportation system supports public safety and national security. As the results of this research have been implemented on railroads throughout the United States, significant safety improvements have been realized. These include:

- **Better performance** through the development of quantitative relations between rail inspection schedules and the damage tolerance characteristics of rail.
- **Improved safety concepts** and criteria for preventing track buckling, including improved maintenance practices that reduce the risk of buckling by avoiding disturbed ballast

conditions and large shifts in the rail's neutral temperature.

- **Development of improved gage retention (rail restraint) requirements** and prototype measurement systems for determining rail restraint capacity.
- **Establishing relationships between track geometry variations and railcar safety** based on experimental and analytic studies to improve specifications for controlling track geometry irregularities.

The Track Systems Research Program interacts with other cooperative government and industry research efforts such as the Vehicle Track Systems Program and the Facility for Accelerated Service Testing (FAST), both heavily involving the railroad community.

The global objective of this Track Systems Research Program is to foster railroad safety and economic efficiency by enabling track engineers to target inspections and maintenance resources based on the actual performance of the railroad track. Specific research tasks are pursued based on historic statistics of accident and maintenance costs and/or based on engineering expectations of potential future problems. Included in the program are research tasks in the areas of **rail integrity, track stability, rail restraint, vehicle track interaction, track degradation, grade crossing safety, and signal system safety**. These interactive efforts provide obvious benefits to the industry, the public, and the FRA in attaining a status wherein the new concepts and results being developed consistently enhance performance and safety in actual service. Hence, the safety research sponsored by the FRA looks toward the kind of upfront cooperative ventures which will maximize likelihood that new requirements and procedures will not inadvertently introduce unacceptable safety hazards.

Following is a brief synopsis of some key research task areas of the Track Systems Research Program.

## Rail Integrity

The initial objective of this task is to **develop the technical foundation for performance based safety standards** that could replace the current standards for inspection of rail and remedial actions to deal with rail defects. The second major objective, currently being addressed, is to **develop the technical foundation for rail integrity improvements** which could be implemented by changing railmaking practices, rail maintenance procedures, and/or nondestructive inspection (NDI) methods.

## Track Stability Research

The track stability research program functions under five major task activities: **Buckling Safety**

**Assessment; Track Resistance; continuous welded rail (CWR) Technology; ERRI/UIC Committee Research in “Improved Knowledge of Forces in CWR Track;” Railway Bridge Infrastructure Research.** The principal goal of this research is to develop criteria, guidelines, and recommendations to improve the buckling safety of CWR tracks.

## Rail Restraint

The principal objective of the rail restraint research activity is to **develop guidelines and recommended practices for inspecting the tie fastener system** for adequate rail restraint capacity to function within acceptable gage widening limits.

# RAIL INTEGRITY

The nation's railroads continue to place increasing demands on their tracks by operating heavier vehicles at increasing frequencies over a concentrated route structure.

Better inspection methodology, guidelines for remedial action, maintenance practice and product quality are the goals of FRA research to assure that rail and metal track appliances can continue to meet these demands safely in the future.

Accomplishments in this area in recent years include the following:

- Models to predict the growth rate of rail defects with particular attention to detail fractures.
- Evaluation of advanced measurement techniques for determining residual stress distributions.
- Guidelines for adjusting the frequency of rail tests based on defect occurrence rate and defect growth characteristics.
- Failure studies of derailments caused by shattered rail which revealed the role of residual stress as a potential threat to rail integrity.
- Technical support reviewing the implications on track safety of permitting delayed remedial action for "non-critical" cracks.
- Experiments to measure rail residual stresses using interferometry and thermal annealing.
- Technical evaluations of the feasibility of electro-magnetic acoustic transmitter technology for application of internal rail flaw detection.
- Upgrades in modeling software to calculate rail residual stresses created from in-service loading.

## Rail Inspection

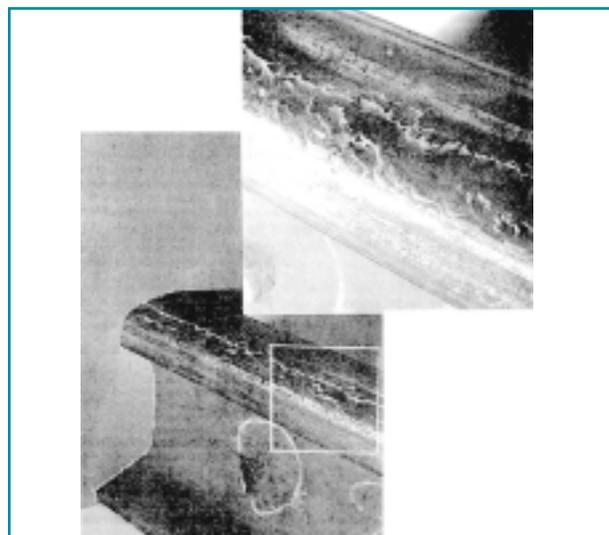
Rail failures, which lead to derailments and unplanned or emergency rail replacements, are costly to the railroad industry.

## RESEARCH STATUS

A potential reduction in costs could be realized through an improved rail inspection program. The first step toward this goal, reported in the 1988-91 research summary, was a program of extensive testing and analysis to determine the rates of growth of typical rail defects. The results have been used to help draft a proposed revision of the Track Safety Standards governing frequency of rail inspection (49 CFR Part 213.237). The Advanced Notice of Proposed Rulemaking was published in 1992, and workshops were held in 1993 to obtain industry comments. The proposed revisions were finalized in 1994, and completion of the rulemaking is pending.

## KEY FINDINGS

In 1991-1992, rail failure-caused derailments involving hazardous material spills prompted the FRA to conduct an in-depth audit of existing rail inspection programs and practices. The Office of Railroad Development provided technical assistance to the audit team, which conducted its review in 1993 and issued its report in 1994. Based on findings from the audit, research on rail inspection has been redirected toward fostering improved defect detection technology. The new objective is to seek inspection methods and procedures capable of



detecting internal rail defects even when buildup of rail lubricant and dirt, or deterioration of the metal rail surface, would obscure such defects from detection by existing means.

The accompanying photograph shows an example of the second condition. The internal defect visible below the surface damage was identified by the National Transportation Safety Board as the cause of a 1992 rail failure and derailment which led to a hazardous material spill.

In 1994, the FRA solicited proposals under the DOT Small Business Innovative Research Program for improved nondestructive inspection techniques which might be applied to the problem of detecting internal rail defects underneath dried lubricant film or surface metal damage.

A Phase I effort was awarded in 1995 to examine the feasibility of electro-magnetic transducers (EMATs) to detect internal defects in rail with heavy surface damage and lubrication. A stationary prototype system was designed and developed that was capable of detecting internal defects as small as 5 percent of the rail head area. A Phase II effort was awarded in 1997 to develop a moving prototype system. The Phase II research is expected to be completed in 1999.

### Better Guidelines for Remedial Action

Revisions to the regulations on remedial action for rail defects (49 CFR Part 213.113) are a part of the rulemaking which is expected to reach completion in 1998.

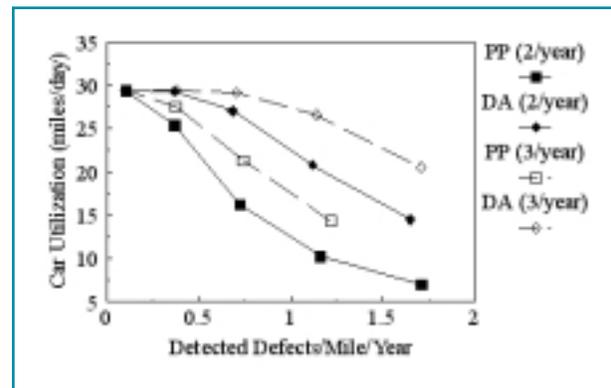
#### RESEARCH STATUS

In response to a petition from a Class 1 railroad to study the concept of delayed action for certain types of rail defects, additional work was undertaken in 1994. Under the delayed action concept, a defect not exceeding a specified size when detected can be left in track with no action required for a specified number of days. The petitioner reasoned that implementation of the concept would improve detector car utilization and increase overall safety. Under the present rules, **immediate action must be taken on every detected defect**. The detector car is often shut down for the day, short of the miles of track it

could have inspected, because the rate of progress is limited by the capacity of a chase gang to make repairs. Applying the delayed action concept, the chase gang and detector car could concentrate on the more dangerous larger size defects, and mark the small ones for later action by a second gang.

#### KEY FINDINGS

Based on results from the 1988-91 research program, **it is possible to establish a safe delay period during which a small defect may grow slowly under the influence of traffic but will not pose a risk of rail failure.**



The potential benefit has been estimated by means of a risk/benefit analysis computer program which was developed to simulate the rail inspection process with or without delayed action. The accompanying graph shows an example result for a hypothetical medium-density freight line carrying 60 million gross tons and inspected 2 or 3 times per year. Detector car utilization (miles inspected per day) is plotted versus average annual rate of defect detections. The simulations with delayed action (denoted as DA) and under present practice (denoted as PP) show that the detector car utilization falls as the annual defect-detection rate increases. The simulation, however, also demonstrated the potential benefit in terms of the increased car utilization in number of miles inspected per day, if delayed action is allowed for internal defects not exceeding 25 percent of the rail head area.

The FRA granted a test waiver to a Class 1 railroad to carry out the delayed action concept for non-critical defects in December 1995. This test waiver will expire in December 1998. During this time, evaluations of the delay action concept will continue

based on defect statistics recorded during the waiver period. The simulation model for detector car utilization will be correlated with these data to reflect more accurate inspection/repair performance.

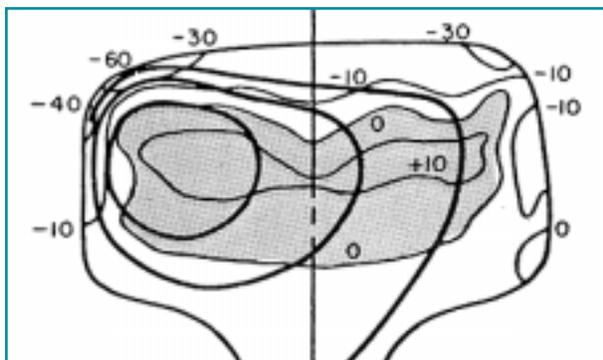
## Better Guidelines for Rail Grinding Practices

Research on the relation of defect growth rates to residual stresses suggests a connection to maintenance work performed by grinding to control wear and profile.

In 1991, a Class 1 railroad was suddenly faced with an abnormal number of rail failures on one particular line which was due to the formation of internal defects unusually close to the gage corner. These defects also grew so much faster than normal that the railroad had to increase the frequency of rail inspection from several times per year to twice monthly in order to maintain safe operations.

### RESEARCH STATUS

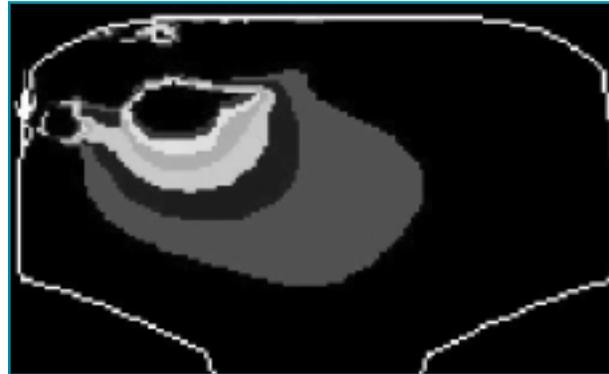
In a search for possible causes, implementation of rail grinding at some time before the appearance of unusual defect behavior was identified as the only significant change. In the accompanying figure, the heavy rings outline the progression of a normally growing internal defect which was monitored in an experiment at the TTC. The shaded area



indicates where residual tension, measured in the same rail, has apparently influenced the progression of the defect.

In view of the important role played by residual stress, FRA has been sponsoring the development of an advanced numerical analysis method for estimation of rail residual stresses in service. Work in progress was covered in the 1988-91 summary report. The accompanying figure shows a result of

applying the method to a case in which the wheel/rail contact loads were disposed so as to represent the effects of the grinding cycle mentioned above. Residual tension, indicated by the shaded areas, is concentrated near the gage corner. The



analysis thus confirmed the hypothesis that the grinding cycle had caused the defect problem. This result was communicated to the industry in 1992.

Additional experimental and theoretical research was undertaken in 1993 to assist the industry in evaluating alternative grinding cycles. Test zones were established in the FAST High Tonnage Loop for the conduct of grinding trials. Standard quality rail was tested during 1993-94. A similar test of head-hardened rail was started in 1994 and was completed in 1995.

At the same time, a laboratory project was undertaken to improve the quality and reduce the cost of experimental stress analysis. The new measurement procedure was developed in 1994 and is now being applied to determine the residual stresses in the standard quality rails. (The effects of the alternative grinding cycles will be compared with effects on rails that were tested with no grinding.) A similar set of measurement programs on head-hardened rail was completed in 1996.

A collaborative effort between the Department of Transportation and the National Institute of Standards and Technology is planned to determine in-situ residual stresses in rail slices by means of neutron diffraction and radiography. Rail slices approximately 1/4-inch thick have been obtained from the FAST rail grinding experiment, and will be used in this joint effort.

## KEY FINDINGS

Also in 1992, discussion with officials from several railroads brought to light a significant difference of opinion on grinding cycles. Some railroads favored frequent light grinding, whereas others favored infrequent heavy grinding. Consideration of revenue traffic density tended to guide the preference, but the experience with defects close to the gage corner suggested that a study of the effects of different grinding cycles on rail performance would be worthwhile. The findings from earlier research suggested that grinding too heavily could concentrate excessive residual tension in other parts of the rail head.

## Improvement of Rail Production Quality

Roller straightening, commonly the final step in production of modern rail, is another source of residual stress which can affect rail performance in service.

## RESEARCH STATUS

Earlier research mentioned in the 1988-91 summary report led to guidelines on control of roller straightening for prevention of excessive stress. These guidelines were disseminated to the industry in 1992. Plans for additional research on this topic began in 1997, when better estimates of roller straightening stress could be factored into the estimation of residual stress after service.

In 1993, the railroad industry expressed dissatisfaction with the performance of cast switch frogs in freight service. These appliances generally do not last for more than 350 million gross tons of heavy freight traffic, which on some very high density lines can be as little as 2 years. It is theoretically possible to make much longer lasting frogs by changing to a much harder and stronger alloy, provided that care is taken to preserve resistance to cracking and fracture. FRA responded by sponsoring laboratory research to determine the feasibility of producing steel with greater strength and better fracture and impact resistance. Results from the feasibility study suggest that such improved material properties can be achieved through thermo-mechanically controlled manufacturing processes and proper selection of alloy additives.

## FUTURE RESEARCH

The research and development for rail is focused on the possibility of combining low cost alloying with advanced heat treatment techniques to achieve the desired mechanical properties. In 1994, work began on the development of methods for evaluating candidate heat treatment procedures and indicating whether or not the resulting metallurgical properties would be likely to yield the desired benefit without risk of low resistance to cracking and fracture. Basic analytic methods became available for application in 1996. Starting in 1997, it was planned to integrate this project with similar efforts aimed at improving the performance of wheels and plate stock used in tank car construction. It is also planned to expand the integrated program to include development and conduct of scale tests for experimental evaluation of alloy and heat treatment combinations.

Over the next several years, planned research includes the following:

- continue to develop and maintain tools and conduct analytic studies to establish rail defect growth rates as a function of service environments;
- evaluate the effectiveness of advanced inspection techniques, fabrication processes, and alternate inspection and repair programs in the control and potential reduction of rail in-service failure rates;
- maintain expertise in areas of failure mechanics and inspection techniques for predicting and detecting formation and growth of rail defects;
- develop a simulation model for detector car utilization as a tool to evaluate the potential benefit of delayed remedial action in terms of increased track miles tested;
- evaluate grinding experiments on rails with higher Brinell Hardness at FAST/HAL;
- evaluate the effect of rolling-contact on the fatigue-resistance of advanced steels;
- validate residual stress model for in-service loading; and,
- evaluate delayed remedial action repair and non-critical defect concept for rail testing.

# RAIL RESTRAINT

Over the last 5 years, the number one cause of track-related derailments in the United States was failure of track to maintain gage due to missing or defective ties and fasteners.

The railroads spend approximately \$1 billion per year on track inspection and tie replacement to combat this problem. A research goal of the rail restraint task under the FRA's Track Research Program has been to develop a continuous inspection technique which can identify critically weak track.

Track inspection is currently performed visually, on foot or from highway-rail vehicles, and mechanically, using track geometry-measuring vehicles. **Visual inspections of cross ties are largely subjective.** Equally competent inspectors, acting independently, may reach widely different conclusions concerning the condition of any group of cross ties depending on each individual's training and experience.

## Gage Restraint Measurement System Development

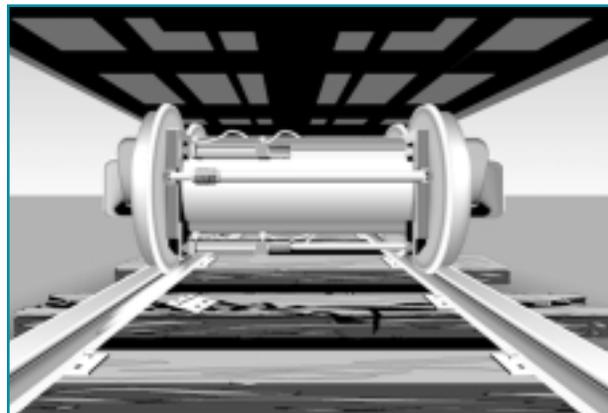
The Gage Restraint Measurement System (GRMS), developed by the Volpe Center, and Ensco, Inc. in cooperation with the railroad industry and the FRA, is the first continuous tie inspection system that automatically detects locations where rail restraint is inadequate.

The GRMS train is made up of a half-loaded 100-ton (90,718-kg) hopper car on loan from the Union Pacific Railroad, and an instrumentation car pulled by a locomotive. The hopper car is equipped with two gage-measuring systems. The special telescoping axle, used to measure loaded gage, is mounted in a standard three-piece freight truck which fits under the hopper car or any conventional 100-ton (90,718-kg) capacity freight car. The instrumentation car carries all the computer, signal processing, power supply, and support systems equipment.

The GRMS first measures track gage in its unloaded state using a conventional contact gage

system similar to that used on many track geometry cars. The 7-ton gage widening load is then applied by a wheelset on a telescoping axle installed as the first axle of the trailing truck of the hopper car. The loaded gage is measured directly from the displacement of the telescoping wheelset. Loaded and unloaded gage measurements are taken *every 12 inches*, and are then compared to provide calculated indications of track strength against gage-widening loads.

Two significant indications are provided. The projected loaded gage is the calculated gage under predicted heavy lateral loads and normal vertical loads. A track location is considered a *high risk for derailment* when the projected gage exceeds a critical limit. The second indication, gage widening, shows the relative stiffness of the track, and predicts locations of *possible future weakness*.



Gage Restraint Measurement System Device

The quantitative measurements of track strength performed by the GRMS provide a continuous record of track condition and comparisons against defined thresholds. Comparing the measurements obtained from a sequential series of surveys will permit evaluation of overall track quality and the effects of time, traffic, and maintenance work on the strength of the track.

## RESEARCH STATUS

Some of the accomplishments in this area include the following:

- Researching FRA rulemaking initiatives concerning standards for gage restraint measurement.
- Improving GRMS hardware and software to enhance speed and accuracy of outputs.
- Developing data for use by the FRA and providing information to the FRA Office of Safety related to a waiver request submitted to the FRA.
- Demonstrating the use of Gage Restraint Measurement System (GRMS) on operating railroads. Defining performance requirements for an alternate configuration GRMS proposed by the railroads for their independent use.
- Assessing the performance of and analyzing the data gathered by GRMS test vehicle, developed by the Railroad Industry based upon the FRA prototype.
- Developing Track Data Alignment System software for post-processing of GRMS data.
- Providing support to the FRA's Office of Safety and the Track Safety Standards Working Group for implementing the GRMS as a performance-based standard in revisions to the track safety standards.

## KEY FINDINGS

The GRMS provides a performance-based evaluation of rail restraint capacity by directly applying a lateral test load between the rails and measuring the resulting widening of gage. The test load is kept to a sufficiently low level that the track is not damaged by the process.

Extrapolations from the gage measurements under the test load project the potential gage widening under severe lateral loads that could occur under a train. The GRMS locates and marks locations at which the potential widening of gage could be sufficient to allow the wheels of a locomotive or car to drop between the rails.

## GRMS Technology Transfer

Under this program, the FRA has made a concerted effort to transfer the developed GRMS technology to the industry.

Production of an informational video tape, presentations and papers given at industry conferences, and equipment demonstrations were the key tools used to disseminate the technology to the railroad community. At the request of industry equipment suppliers, the FRA made available the complete design plans and software of the system to companies actively pursuing hardware development.

## RESEARCH STATUS

- Performance requirements have been defined for alternate configuration of GRMSs proposed by the railroads for their independent use.
- The use of GRMS has been demonstrated on operating railroads.
- Tests have been conducted and data evaluated in support of revisions to rail restraint standards for gage widening mitigation.

## KEY FINDINGS

Many carriers have made substantial commitments to advance the technology by developing their own equipment and by supplying track time and personnel for FRA equipment. One carrier was issued a regulatory waiver by the FRA Office of Safety to implement the technology on over 400 miles of track. This waiver relaxed specific regulations that are addressed by conducting a GRMS inspection. To assure safety, a performance-based regulation was implemented. As a result, improvement was measured in the physical track condition and the railroad gained confidence in applying the new technology.

## FUTURE RESEARCH

It is expected that more carriers will exercise the waiver process until the current regulations can be updated to incorporate the new performance-based methods. Rail restraint inspection technology is advancing very rapidly.

As each railroad develops its own system, the variance in size, weight, loading configuration, and measurement intervals creates a level of uncertainty in each system's ability to locate defects. If the railroad intends to use the system in a regulatory mode, the FRA must be assured that the system is performing at consistently acceptable levels. Rail restraint research includes investigation of procedures used to verify inspection vehicle performance, track degradation growth rates, inspection interval requirements, and maintenance planning technologies. As inspection technologies for finding the track defects which cause derailments are advanced, positive results will include improved railroad safety and efficiency and an increased abil-

ity to predict, with confidence, that a critical gage-widening defect will not surface before the next scheduled inspection.

Research planned for the next few years includes the following topics:

- continued revenue track surveys of U.S. railroads;
- alternative performance-based inspection standards;
- track degradation rates and inspection interval determination; and,
- GRMS performance verification procedures.

## TRACK LATERAL STABILITY

---

The use of continuous welded rail (CWR) tracks in the United States is increasing, bringing with it a potential increase in the number of train derailments induced by track buckling. Track buckling can cause catastrophic derailments because incipient buckles are difficult to predict and detect, and most often occur under dynamic conditions, (i.e., under the train).

The FRA conducts, with the support of the Volpe Center, experimental and analytic investigations to develop preventive measures against track buckling, and ultimately to reduce the number of catastrophic buckling incidents.

Track buckling is the “**sudden**” **formation of large lateral misalignments** caused by a combination of several factors which include the following:

- **high compressive forces** generated by stresses due to thermal and mechanical loads;
- **weakened track conditions** typically attributed to inadequate track lateral resistance, excessive lateral alignment deviations, and decreased rail neutral temperature; and
- **vehicle loads** which include vertical, lateral, and longitudinal wheel forces.

Current CWR laying methods utilized by the railroads to minimize the risk of track buckling are largely empirical. The guidelines currently used by the U.S. railroads are the American Railway Engineering Association (AREA) recommended practice, which specifies a laying temperature range based on deviations from the expected mean temperature.

The problem is further complicated by deviations of the neutral temperature from the rail installation temperature. A large reduction in the rail neutral temperature could lead to buckling. Track maintenance-of-way engineers need guidelines and procedures to assess neutral temperature variations and to develop economic methods to increase the buckling strength of CWR tracks, thereby reducing the risk of incurring catastrophic derailments.

### RESEARCH STATUS

To address these issues, research efforts are underway to develop guidelines, methods, and strategies to prevent track buckles.

FRA-sponsored research has resulted in the following major accomplishments:

- Development of a track buckling safety analysis methodology and “track quality”-based safety criteria.
- Development of “CWR-BUCKLE,” a user-friendly, PC-based, interactive analysis program for buckling strength and safety evaluations.
- Performance of CWR concrete tie track lateral strength evaluations to quantify governing parameters, including consolidation rates, track maintenance influences and revenue service conditions.
- Performance of CWR longitudinal resistance tests and analyses to evaluate rail/tie fastener longitudinal response characteristics.
- Evaluation of CWR “destressing and readjustment” mechanics, and development of improved requirements for enhanced neutral temperature maintenance.
- Exchange of interactive research and technology with the European Rail Research Institute on track lateral stability, rail longitudinal force measurement, CWR and bridge interaction, and improved CWR buckling safety criteria.
- Development of “CWR-INDY,” an ultra-user-friendly tool for track buckling evaluations for industry use and application.

### KEY FINDINGS

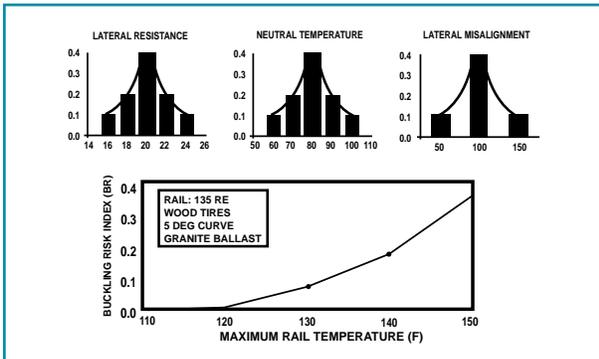
**Risk Analysis Tools** - The results of the above research to date have led to a much improved understanding of CWR buckling behavior, and to the development of prototype guidelines and criteria for buckling prevention. These guidelines and criteria are applied to buckling safety evaluations



through the user-friendly “CWR-BUCKLE” model. This model is a versatile tool for CWR track buckling analyses and safety predictions for industry

**Measuring Track Resistance** - The actual industry application of buckling safety limits and concepts to a large extent also depends on a knowledge of track lateral resistance and on an adequate control of rail longitudinal force. In line with these requirements, techniques have been developed and prototype hardware is available for the measurement of track resistance using the Single Tie Push Test (STPT) device which has recently been redesigned for concrete tie applications.

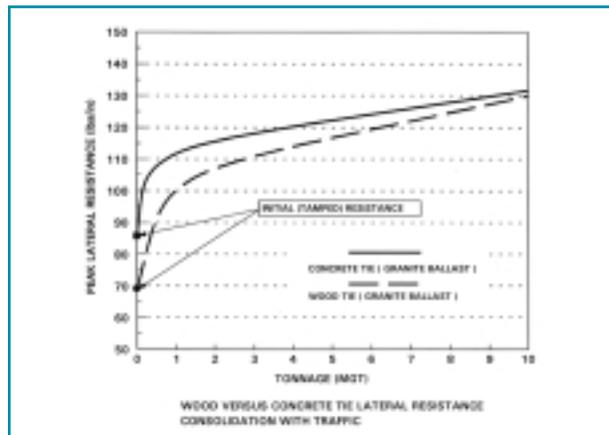
applications and engineering assessments. Recent application of “CWR-BUCKLE” included the development of prototype methodology for evaluating “risk severity”-based buckling potential. Full-scale dynamic buckling tests also have been conducted for safety criteria development and model validation.



STPT Device for Concrete Tie Lateral Resistance Measurement

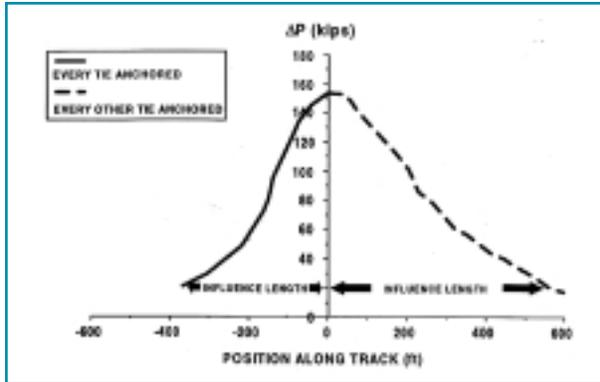
Tests have recently been completed to monitor and quantify the behavior of concrete tie track resistance and its rate of consolidation with traffic. The resulting information enables an assessment of new or recently maintained track conditions, improved requirements on temporary speed restrictions, and a comparative assessment of wood versus concrete tie track buckling strengths.

“CWR Buckle” Risk-Based Buckling Analysis



Full-Scale Dynamic Buckling Tests for Safety Criteria Validation

Wood Versus Concrete Tie Lateral Resistance Consolidation with Traffic



Rail Distress Test: Anchor Pattern Influence on Rail Force Change After Rail Cutting

**Improved CWR Maintenance Practices** - The issue of controlling rail longitudinal force (or neutral temperature variation) also has been addressed through recent experimental and analytic studies. These consisted of field test investigations on longitudinal force change and response behavior in winter rail break and summer distress/rail cutting scenarios, and assessments of effectiveness of repair and readjustment practices on CWR wood tie tracks. The influence of rail anchor's longitudinal restraint on the "influence zone" is shown in the accompanying figure. Similar studies quantifying CWR/concrete tie longitudinal restraint characteristics and distress requirements also are being performed.

## FUTURE RESEARCH

Research to enable the development of criteria, guidelines and specifications for the buckling prevention of CWR tracks, and the required diagnostic techniques for the detection of incipient buckles

and buckling-prone conditions is continuing. These goals are in line with the FRA, AAR and industry goals for an overall "improved infrastructure" which enhances safety and improves efficiency and productivity at lower overall life cycle costs, thereby ensuring a "more seamless" transportation network.<sup>1</sup> Since the "track of the future" was identified with concrete ties,<sup>2</sup> ongoing and new research will emphasize the stability of CWR concrete tie tracks, and improved procedures and criteria for CWR installation, maintenance, and repair. Specific activities are expected to focus on:

- continued analytic and experimental investigations of buckling behavior and stability enhancements of CWR concrete tie tracks;
- continued development of concepts, techniques, hardware for the determination and control of rail longitudinal force and neutral temperature variation;
- development and evaluation of remote sensing gages for monitoring CWR neutral temperature;
- development of improved safety criteria, guidelines, and inspection and maintenance practices for preventing buckling of both wood and concrete tie tracks; and,
- evaluation of increased axle load and high speed influences on track stability and buckling and extension of buckling safety criteria for high-speed applications.

<sup>1</sup> *Railroad Freight Transportation Research Needs, Proceedings of a Conference, Bethesda, Maryland, July 12-14, 1993, Transportation Research Board*

<sup>2</sup> *Wise and Lalonde, Future Trends and Visions in Transportation and Logistics: Research Community's View, Ibid.*

# TRACK LATERAL SHIFT FOR HIGH-SPEED RAIL APPLICATIONS

The “lateral strength” or load capacity of CWR track is a key requirement in retention of track alignment for safe train operation. Track lateral shift can be defined as “the formation and growth of lateral track misalignments due to high L/Vs (lateral to vertical load ratios) and longitudinal forces. Depending on the magnitude of the resulting misalignments, derailments can occur, or ride comfort can be compromised.

The growing trend throughout the railroad industry toward higher speeds and heavier axle loads tends to exacerbate the problem of track lateral stability. Existing high-speed rail systems in Europe and Japan, as well as high-speed rail technology endeavors in the United States such as those proposed for Amtrak and the Florida Department of Transportation/Florida Overland Express (FDOT/FOX), invoke the question of lateral strength adequacy.

## RESEARCH STATUS

The determination of “allowable” L/Vs to limit lateral misalignments to “admissible” levels forms the basis of track lateral shift safety criteria. The FRA, with technical support from the Volpe Center, has initiated a research program to address the overall track shift problem. The intent of this research effort is to conduct the necessary analytic and experimental studies to quantify the lateral shift mechanism under dynamic and thermal loads, and to develop applicable safety criteria and requirements for limiting track lateral shift. These safety criteria can be based on one of the following provisions:

- High-speed track under maximum expected thermal loads should, for a given vehicle, have minimum lateral strength to limit the development of lateral misalignments to within a specified value,  $d_L$ .
- Lateral loads generated by high-speed vehicles operating under maximum speed, cant deficiency, thermal load, and initial line defect conditions should not cause the “allowable” deflection limit,  $d_L$ , to be exceeded.

The principal goal of the research program is to “quantify” the above statements by defining values of “allowable” L/Vs or “allowable”  $d_L$ s.

Research conducted to date has led to a much improved understanding of the track lateral shift mechanism, a quantification of the key parameteric influences, and to the development of prototype guidelines and criteria for track shift mitigation. Specifically, this research has resulted in:

- identifying the track shift mechanism as a “moving load problem” with many influencing parameters (i.e., generation and growth of misalignments depend on the applied L/V’s, number of axle passes, the track’s “loaded” and “unloaded” lateral resistances, rail longitudinal force, and track curvature);
- determining that, for a set of fixed L/V and track parameters, the resulting lateral misalignments could be “stable” (i.e., reach a finite value) or “unstable” (i.e., continually growing) as a function of the number of axle passes;
- developing a comprehensive analysis methodology for prediction of vehicle loads and track lateral shift as a set of coupled vehicle/dynamics and track lateral response analysis models;
- conducting parametric studies for the evaluation of key track and vehicle parameter influences on track shift including the influences of track lateral resistance, varying L/V ratios, thermal loads and track curvature;
- developing prototype concepts and safety criteria for track shift mitigation based on “levels of safety desired;” and
- conducting model validation studies against benchmark analytic solutions, and preliminary field test validation studies against Track Loading Vehicle (TLV) based repeated load tests.

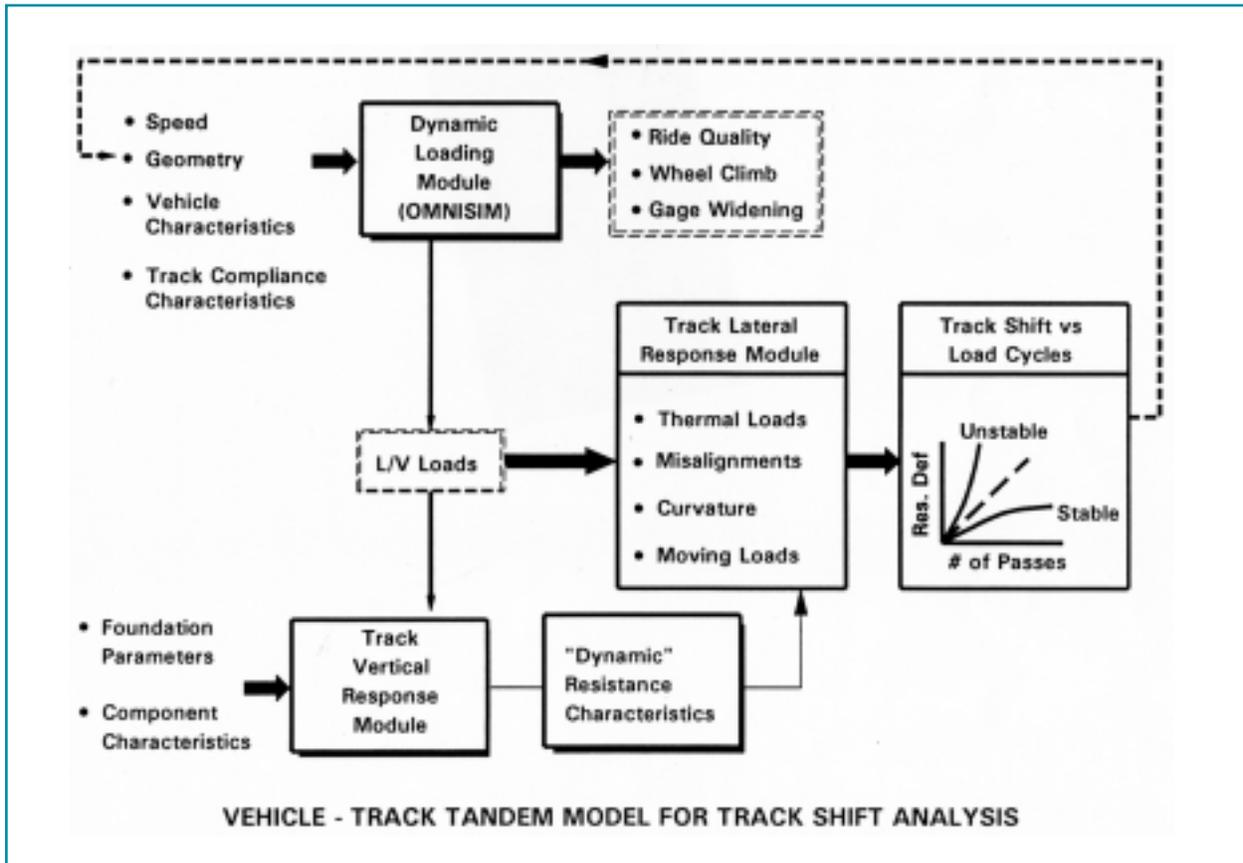
KEY FINDINGS

**Vehicle Tandem Model** - The key component of this work is the vehicle-tandem model for track shift analysis. This model combines the elements of a vehicle dynamic module called OMNISIM with a track lateral response analysis module called TREDA.

OMNISIM is a general purpose vehicle/track dynamic simulation code which predicts lateral and vertical wheel/rail interaction loads, vehicle and track accelerations, and resulting failure conditions such as wheel climb and truck hunting. A novel

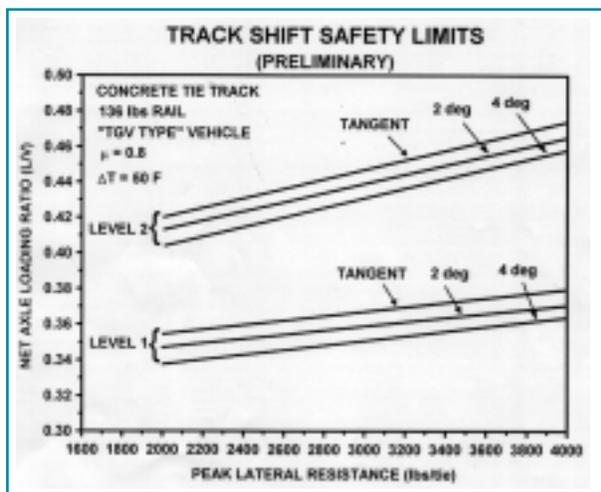
feature of OMNISIM is the incorporation of track flexibility in the simulation code for a more accurate prediction of vehicle dynamic behavior. OMNISIM also functions as the L/V load predictor for the track lateral response module.

TREDA is a two-dimensional track beam model which accounts for moving loads, misalignments, thermal loads, and curvatures, and predicts cumulative lateral deformations as a result of the number of L/V passes.



Vehicle-Track Tandem Model for Track Shift Analysis

**Track Shift Safety Limits** - The application of the vehicle-tandem model for track shift predictions led to the development of prototype safety criteria for track lateral shift mitigation. These criteria are postulated on Level 1 or Level 2 Safety based on the “permissible” residual lateral deflections allowed. Level 1 allows no (or very small) misalignments, while Level 2 allows permanent set prescribed by the “maintenance limit” which is typically on the order of 5 mm (0.2 inch) for high-speed passenger operation. These prototype track shift safety limits prescribe the “allowable net axle force ratio” as a function of track lateral strength for a given passenger vehicle as shown in the following figure.



Peak Lateral Resistance (lbs/tie) Track Shift Safety Limits (Preliminary)

## FUTURE RESEARCH

Further research in this area will focus on:

- conducting comprehensive parametric studies of track lateral shift for different high-speed (vehicle) applications and conditions;
- finalizing baseline safety requirements and safety criteria for track shift mitigation;
- developing a user-friendly, PC-based, interactive version for track lateral shift analysis model (SHIFT), and for the vehicle/track dynamics model (OMNISIM); and (TREDA); and
- conducting model verification through field test validation studies.

## FACILITY FOR ACCELERATED SERVICE TESTING

---

The FAST Heavy Axle Load (HAL) Program, jointly funded by the AAR and FRA, is measuring the effects of 39-ton axle loads (315,000-pound gross vehicle weight) on track performance and the benefits of improved suspension trucks on 39-ton axle load performance. The focus of the HAL implementation program is safety. The program is managed at TTC by TTCI for the industry and the FRA. The research is conducted to examine the effects of increased axle loads on track, subgrade and structures, and to develop and test improved techniques to measure, manage and minimize these effects. These techniques will help ensure that as axle loads increase, they will not compromise safety operations.

### RESEARCH STATUS

After 460 million gross tons (MGT) of service during phases I and II of the HAL Program, results indicated that operation with 39-ton axle loads

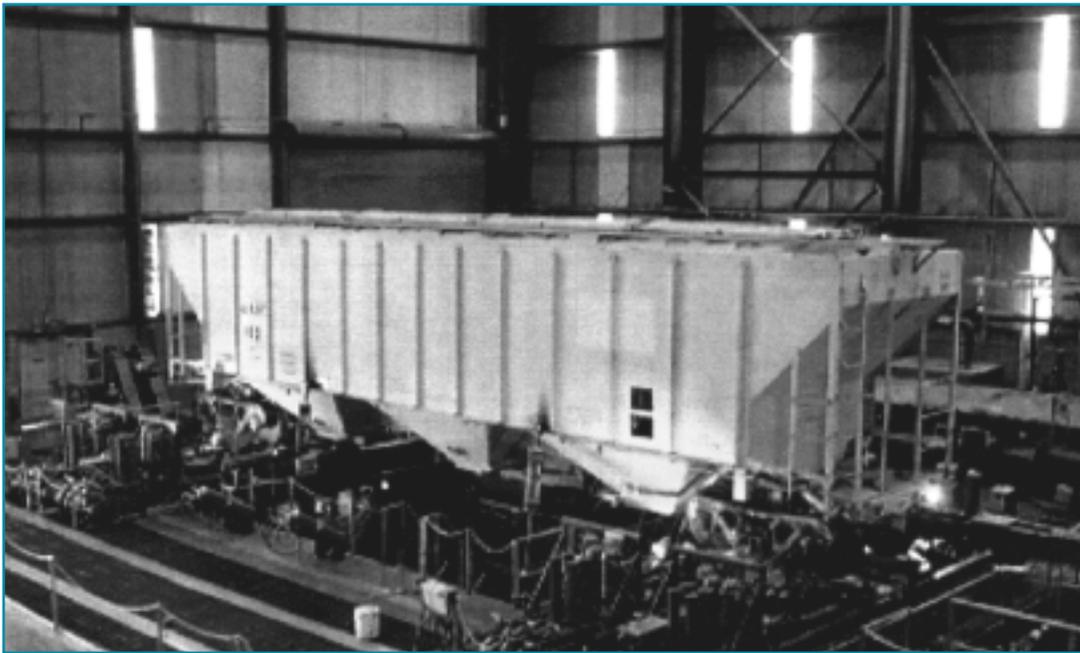
was technically feasible. Using premium material, especially head-hardened rail and high-integrity frog castings, would improve the safety, efficiency and economics of heavy axle load operation.

Phase III of HAL has accumulated nearly 300 MGT by the end of 1997 and is investigating the benefit of improved suspension systems on overall heavy axle load safety and economics. Initial results suggest that improved suspension trucks do provide benefit by reducing fuel consumption, decreasing wheel/rail wear and reducing overall track damage.

### FUTURE RESEARCH

It is intended to keep accumulating tonnage through 1998 until 450 MGT are achieved. It is planned to research alternative substructure improvement techniques and monitor revenue service performance to validate HAL results.

# VEHICLE/TRACK INTERACTION





## VEHICLE/TRACK INTERACTION

---

The principal objective of the Vehicle/Track Interaction research effort is to quantify rail vehicle response to track geometry in order to **develop improved approaches to track geometry inspection and maintenance** that are both cost effective and safety enhancing, to **develop modifications to vehicles susceptible to derailment**, and to **develop methodologies for evaluating new vehicle designs** for safe dynamic behavior.

The program to conduct studies of vehicle response to track geometry was developed by the FRA. In addition, some of the results of these efforts are used in studies of gage restraint, track buckling, and rail fatigue. This program is being conducted through cooperative research efforts with the industry and has promoted information exchange among members of the industry and the Government.

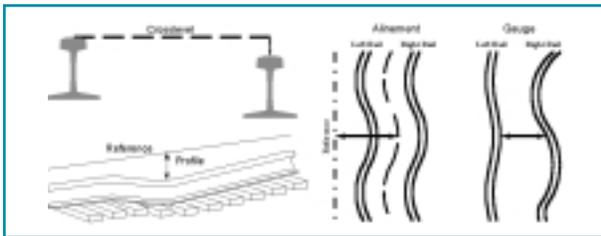
Benefits from this FRA Vehicle/Track Interaction Program, covering the major track failure modes, can be expected on several levels. The most important will be fewer unexplained derailments caused

by adverse interaction of track, vehicles and operations. Additionally, the research results will provide information necessary to improve industry specifications and recommended practices, as well as aid the FRA in possible rulemaking activities. Further, results have already been incorporated into several railroads' operating and maintenance practices promoting safer track, equipment, and operations.

Track surface geometry is described by **track profile** and **crosslevel**. **Rail profile** is the elevation of the rail relative to a fixed reference line. **Track profile** is the average of the left and right rail profiles while **track crosslevel** is the difference between the left and right rail profiles. **Track alignment** — the direction or 'route' of the track — and **gage** — the distance between the two rails — are required to completely describe track geometry. Track surface and alignment characteristics vary with distance along the track. Because of the nature of track construction, track geometry variations can be repetitive or can be isolated single events.

## TRACK GEOMETRY - VARIATIONS

Excessive variations in any of the four track geometry characteristics can lead to a derailment.



In addition, track geometry variations can cause large lateral rolling and vertical bounce motions of vehicles, and can induce large lateral and vertical forces between the wheel and the rail. These motions and forces can be oscillatory. The motions and forces might vary as the vehicle travels on the track, causing buildup of resonant motions of the vehicle, or they might be single events, occurring only once at a particular track location as each vehicle passes.

### RESEARCH STATUS

The initial approach used in the program to study track geometry emphasized use of derailment scenarios that could be associated with a high number of accidents caused by track geometry variations and irregularities. As a result, these studies focused on harmonic roll associated with high center of gravity cars operating on half-staggered bolt-jointed rail of 39-foot lengths. This scenario is characterized by a low-speed (10 to 20 mph) derailment of a car having a truck center spacing of less than 45 feet. Both government and industry developed simulation programs to predict harmonic roll response. Predictions made with these simulation programs have shown good agreement with field and laboratory test data.

After developing an understanding of harmonic roll, the approach was broadened to include all scenarios involving track surface geometry. The conditions studied include car body rollover due to the harmonic roll response of freight vehicles to repeated crosslevel variations, wheel climb derail-

ment and carbody/truck separation due to track twist, wheel climb derailment due to excess superelevation in curves, and carbody/truck separation and truck loading in excess of design limits due to the harmonic bounce response of a rail vehicle to repeated track profile variations.

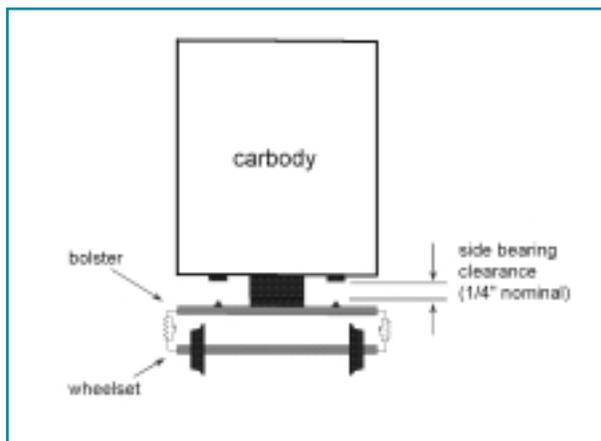
The FRA has developed algorithms based on the response of an idealized vehicle model to the track surface geometry. These algorithms can distinguish between a single geometry perturbation with a relatively large amplitude, which is a safe track condition, and repeated geometry perturbations each with a relatively small amplitude, which is an unsafe track condition. The algorithms require multiple measurements and extensive computations before comparison to maximum values. The algorithms can identify track segments having small amplitude periodic irregularities capable of producing resonant response that could produce wheel lift, centerplate separation or coupler separation, without rejecting track that is consistent with current good practice and has been demonstrated to be safe.

The track surface geometry algorithms have been implemented in a computer program and applied to typical track geometry car data. This program has been used to analyze data taken with the T-10 inspection car, operated by the FRA, as well as with railroad track geometry cars. Currently, the algorithms are being implemented in a system which can measure and evaluate track surface geometry in real-time. The real-time implementation of the track surface geometry measurement and evaluation system is being accomplished by updating and refurbishing the T-6 track geometry measurement instrumentation, acquiring the necessary computer hardware and software for evaluation, storage, and display of the track geometry data, and development of the software necessary for data acquisition and display. The track surface geometry algorithms require track alignment, crosslevel, and profile for evaluation.

A typical freight car suspension is provided by 3-piece freight trucks at either end of the carbody, comprised of a bolster, 2 side frames, and 2 axles. The carbody rests on the bolster at the centerplate, and is able to pivot about the edges of the centerplate. Side bearings on either side of the centerplate provide a stop to relative roll between the carbody and the bolster. Side-bearing clearance is the clearance between the carbody and the bolster at the side bearing. Each end of the bolster rests in a side frame, supported vertically by the spring group, in parallel with some auxiliary friction device, usually a snubber.

### KEY FINDINGS

In studies conducted by the Office of Railroad Development, it was found that some light weight freight cars traveling over track with large twist (difference in crosslevel between truck centers) in curves would experience lateral-to-vertical force ratios on the lead outer wheels of the truck that were in excess of established wheel climb derailment cri-



teria. These results were confirmed by AAR tests on the “bunched spiral” associated with the tests for New and Untried Cars prescribed by Chapter XI of the AAR Manual of Standards and Recommended Practices. An option for increasing the tolerance of freight cars to track twist is to increase the side-bearing clearance. However, increasing the side-bearing clearance has the potential for changing the roll response of a freight car to repeated crosslevel variations. Initial simulation studies indicated that increasing side-bearing clearance could also have the beneficial effect of reducing wheel unloading and reducing carbody roll response. This result was

contrary to railroad industry experience and earlier studies. In order to resolve the differences between the initial numerical simulation results and the industry experience and to provide an improved calibration of a simulation model for predicting the influence of side-bearing clearance on freight car roll response, a series of tests were performed at the TTC in Pueblo, Colorado. Tests on a loaded 100-ton hopper car were conducted on the Vibration Test Unit (VTU) and the Precision Test Track (PTT) at TTC in September and October 1993.

### Dynamics of Wheel Climb

In 1994, the AAR and FRA began a jointly-funded research program to examine the mechanics of wheel climb (also called flange climb) derailments. The AAR conducted the tests using its Track Loading Vehicle (TLV) at the TTC. The primary objective of this testing was to reexamine the current wheel climb criteria used in Chapter XI of the AAR’s Manual of Standards and Recommended Practices and was the first time full-scale testing of wheel climb had been performed in North America.

During testing, controlled wheel climb derailments of an instrumented test wheel set were achieved under a range of applied wheel/rail forces, wheel set angles of attack, rail profiles, and lubrication conditions.



### TLV Wheel Climb Test

### RESEARCH STATUS

From this testing, the following conclusions have been drawn:

- No changes are proposed to the existing Chapter XI wheel climb derailment limits.

- The wheel/rail coefficient of friction, the maximum wheel/rail contact angle, and the wheel set angle of attack have a major influence on the potential for wheel climb. Small (or negative) axle angles of attack tend to inhibit wheel climb behavior.
- Geometry at the wheel/rail interface is related to the required flanging wheel lateral/vertical force ratio (L/V) only through the maximum wheel/rail contact angle. In this study, the peak contact angle was similar between an AAR-1B wheel profile on both new and curve-worn rails. Therefore, the L/V needed for wheel climb was equal on both new and worn rail test zones.
- Unlike the L/V ratio, the distance required for a wheel to climb is related to the entire wheel/rail geometry. Interaction for a new geometry typically involves large contact angles being active over a significant amount of lateral wheel shift. A worn wheel/rail contact situation may involve large contact angles for only a small amount of lateral wheel shift. In these worn cases, a large L/V event of significantly shorter duration may lead to wheel climb.
- At zero axle angles of attack, currently used criteria have at least 15% conservatism built into them. At angles of attack greater than +15 mrad (0.8°) the current criteria accurately predict test results.
- All tests and New and Untried Cars Analytical Regime Simulations (NUCARS) converged to the current derailment criteria at higher angles of attack (10-15 mrad). High flanging-rail friction during test Series 10 resulted in axle L/V ratios at wheel climb that were lower than the Chapter XI limit of 1.5.
- The flanging wheel L/V ratio necessary to produce a wheel climb is independent of the friction on the non-flanging rail. Although friction on the non-flanging rail may help create a lateral force on the flanging wheel, this non-flanging friction will not affect the critical L/V which must be achieved before a wheel will climb.

- Vertical load unbalance does not affect the critical L/V values. Again, such an imbalance may create lateral forces on the flanging wheel, but the imbalance will not affect the critical L/V which must be achieved before a wheel will climb.

## KEY FINDINGS

It is difficult to control or maintain a constant friction coefficient for any given series of TLV tests. Friction varied from day to day. Future test series to examine critical comparisons of analytical and experimental L/V ratios should be conducted with a constant value of coefficient of friction. Care in cleaning and/or sanding of the rails is very important. Furthermore, after such cleaning, a few break-in derailments should probably be run on the rail surface before beginning a test series. If time permits, additional repetitions of high angle of attack runs should be interspersed within the series to statistically improve the estimate of friction.

## FUTURE RESEARCH

Testing and analysis by the AAR are ongoing at the TTC using the TLV. This effort has been designed to improve the current level of understanding of wheel climb behavior. Technical papers were published and presentations were made on the work at the spring 1997 Joint Railroad Conference of the Institute of Electrical and Electronic Engineers and the American Society of Mechanical Engineers.

## Vehicle Dynamics Training Module

The results of research related to the mechanics of rail vehicle derailments are being applied to development of educational material to provide railroad and FRA personnel with an improved understanding of requirements for track and equipment maintenance to ensure safe operations.

## RESEARCH STATUS

The AAR/TTCI, under direction of the FRA, has produced an educational/safety training video which explains, in layman's language, the mechanics of three categories of freight car derailments: catastrophic, vehicle/track interaction, and human factors. The audiences targeted by this video include railroad operating personnel, track crews,

and FRA inspectors. In particular, this video focuses on:

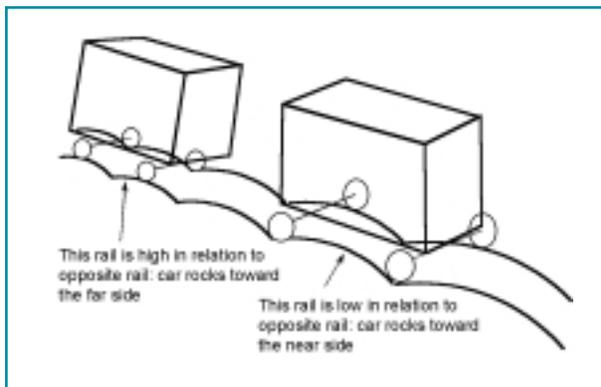
- Basic Dynamics
- Wheel/Rail Interaction
- Wheel/Rail Profiles
- Lubrication Effects
- Car and Truck Design Issues
- Track Geometry Effects
- Track Strength Considerations
- Train Dynamics

This video includes footage of actual derailments and animation generated by the AAR's New and Untried Cars Analytical Regime Simulation (NUCARS) and Train Operation and Energy Simulation (TOES) modeling software. This training video is intended for use as an educational tool in the investigation of derailments, particularly those where no clear causes are evident.

# CAR BODY ROLL RESPONSE

Roll is the rotation of the car body about a longitudinal axis in response to crosslevel variations.

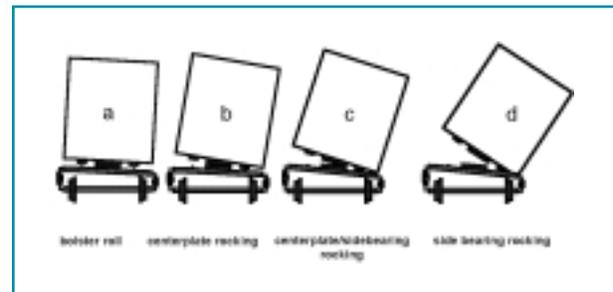
The figure schematically illustrates a car on 39-foot bolt-jointed track with half-staggered low joints. The car starts out with the wheels on one side elevated in relation to the wheels on the opposite side. As the car moves forward, the wheels on one side are lowered while the wheels on the opposite side are raised. At some speeds, the suspension will act to amplify this rolling motion of the carbody, and if the amplitude of the crosslevel variation is sufficient, wheel lift and carbody rollover can occur.



The harmonic roll problem is governed by the non-linear characteristics of the system. Non-linearities arise due to the various support configurations that exist as the carbody extends through its entire range of roll. As the vehicle undergoes harmonic roll, four main roll configurations exist with different roll-moment characteristics corresponding to each roll configuration, resulting in a non-linear effective roll stiffness.

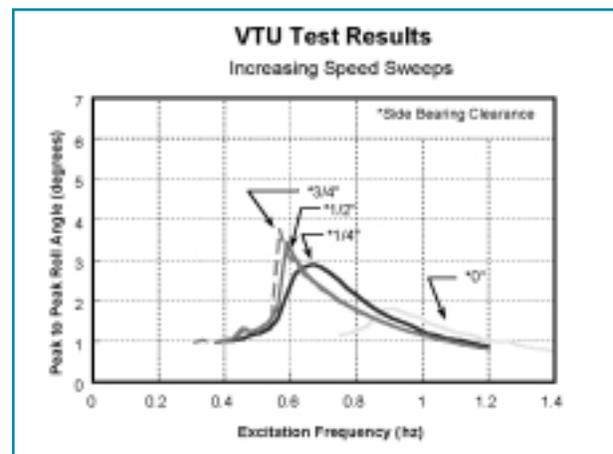
The figure shows the four different roll configurations of a typical freight car. The first configuration, **bolster roll**, occurs when the carbody and bolster rotate together, with no rotation about the edges of the centerplate. **Centerplate rocking** occurs when the carbody rocks about the edges of the centerplate, the extent of this region being dependent upon side-bearing clearance. Further rotation results in **centerplate/side-bearing** rocking as the

carbody contacts the side bearings, further displacing the spring groups. **Side-bearing rocking** occurs when the centerplate completely separates from the bolster, with the carbody rotating about the side-bearing.

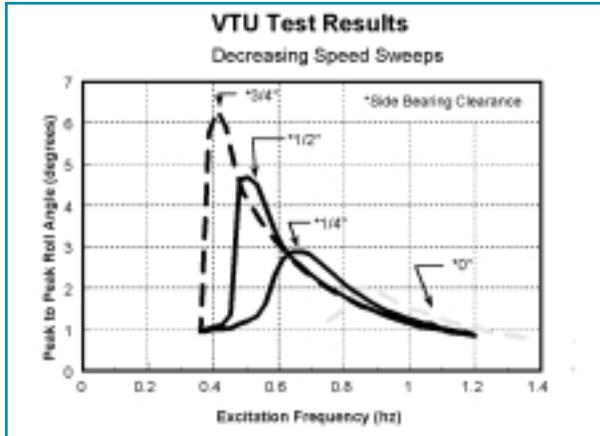


## RESEARCH STATUS

The figure shows a comparison plot of roll response for **increasing sweep** (increasing speed) at side-bearing clearances of 0, 1/4, 1/2, and 3/4 inches with input amplitude of 3/8-inch. The plot shows that the limiting response for increasing speed has been reached at 1/2-inch side-bearing clearance, and further increasing side-bearing clearance to 3/4-inch exhibits the same response. For increasing speed, this figure indicates that side-bearing clearance beyond 1/4-inch has only a small influence on maximum carbody roll angle.



The figure shows a comparison plot of roll response for **decreasing sweep** (decreasing speed) at side-



bearing clearances of 0, 1/4, 1/2, and 3/4 inches with input amplitude of 3/8-inch. This plot shows how the car's behavior differs dramatically as speed decreases, from its behavior with speed increasing. Evident is the increased roll angle as side-bearing clearance is increased, because the softening effect associated with centerplate rocking extends the centerplate rocking region to lower frequencies. Carbody response will continue to increase with decreasing speed in this region, until response jumps down to the linear bolster roll region. No limiting response is reached, with the response being substantially greater at 3/4-inch side-bearing clearance than the response at 1/2-inch side-bearing clearance. For decreasing speed, this figure indicates that side-bearing clearance beyond 1/4-inch has a strong influence on maximum carbody roll angle.

## KEY FINDINGS

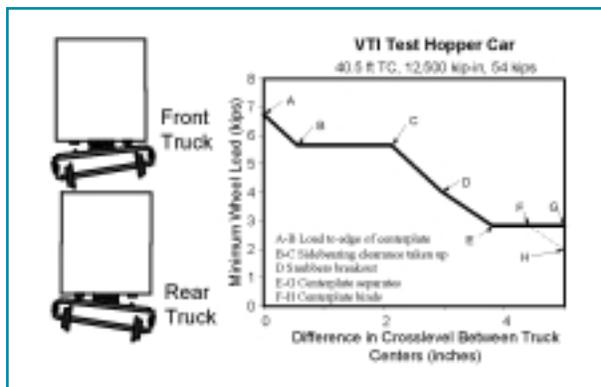
Results of the vibration tests clearly demonstrated the “jump” phenomenon associated with the non-linear behavior of freight car response to crosslevel variations. Tests on the VTU simulating the freight car traversing a series of repeated crosslevel variations while *decreasing* speed produced a much greater roll response than experienced in traversing the same perturbations at *increasing* speed. Tests on the VTU at decreasing speed showed that as side-bearing clearance is increased, carbody roll angle increases.

On-track tests were limited to constant speed runs due to the length of the test section. On-track results show that both 1/4-inch and 3/4-inch side-bearing clearance configurations exhibited wheel lift and maximum peak to peak roll angle in excess of 6 degrees. In addition, the 3/4-inch side-bearing configuration appeared to be sensitive to track anomalies, as evidenced by the sudden jump in response at low speeds. Computer simulations, using a revised model, representing traversal over repeated 3/4-inch low joints confirmed that response at decreasing speed is worse than response at increasing speed. Additionally, as a result of this testing program, it was found that both VTU and on-track testing methods have advantages and disadvantages. Computer simulations can help resolve many issues and provide insight to certain phenomena, but they should not be used alone.

## TRACK TWIST

Curved track is usually superelevated, with the outside rail on a curve higher than the inside rail. In order to obtain the superelevation required for the curve, the outside rail is gradually raised, thereby “warping” or “twisting” the track.

Although “twist” is a design feature, irregularities in the track can cause the twist at the entry and exit of a curve to be greater than designed. Track twist can also occur unintentionally, caused by defects in the track. In addition to causing a crosslevel irregularity, a single low joint causes the track to be twisted.



When a vehicle in good condition is on level track, all the wheels equally share the load. When the same vehicle is on twisted track, the wheel loads are redistributed. The situation is somewhat analogous to a table on a warped floor, which has a tendency to rock between diagonally opposite legs. The suspension of rail vehicles allows them to negotiate some amount of track twist without excessive changes in the load supported by the wheels. The

figure above shows model predictions of the change in vertical load for a hopper car due to track twist.

In addition to carrying the weight of the vehicle, the wheels must also transmit the lateral loads required for the vehicle to negotiate the curve. These lateral loads for curve negotiation can be quite high, even at low vehicle speeds. A wheel with insufficient vertical load and a high lateral load can be forced up and over the top of the rail, thus derailing.

### RESEARCH STATUS

Analytical models have been developed to study rail vehicle response to track twist. Tests have recently been completed at the TTC to ensure that the analytical model can truly predict the behavior of the vehicle and to experimentally determine the safe limits of track twist. The track situations tested included Chapter XI ‘Bunched Spiral’ and the ‘Limiting Spiral,’ entry and exit spirals, curved track with twist perturbation, curved track with alignment perturbation and twist perturbation, tangent track with twist perturbation, and tangent track with alignment perturbation and twist perturbation.

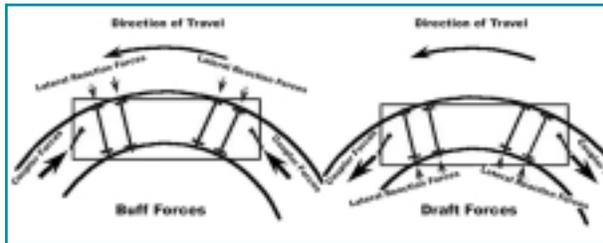
The approach was to test three vehicles which are predicted to be susceptible to wheel unloading due to track twist on tangent, spiral, and curved track with twist perturbations. Wheel unloading as a function of the difference in crosslevel between truck centers was measured during jacking tests performed before the on-track testing. These jacking test measurements were used to verify and adjust the track conditions to be tested. After the first series of tests had been run, a second series was run in which an alignment perturbation was added to the track in addition to the twist perturbation.

# LATERAL AND VERTICAL TRAIN FORCES

Train handling produces longitudinal train forces owing to train action as the train is accelerated and braked.

These train forces can result in significant lateral forces when the train traverses a curve. During braking, buff forces can increase the lateral forces acting on the high rail sufficiently to allow a wheel to climb the high rail, and during acceleration, draft forces can increase the lateral forces acting on the low rail sufficiently to cause the low rail to roll over.

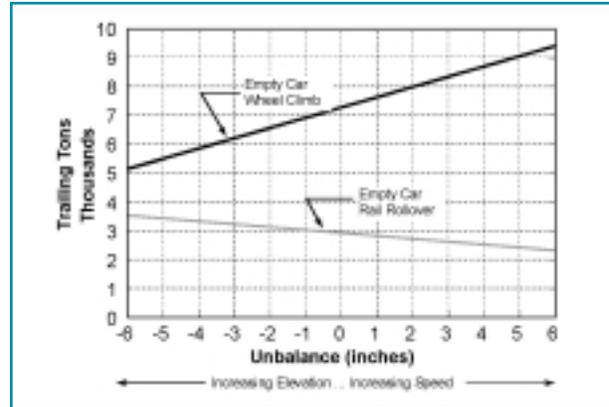
The figure shows buff and draft forces and their lateral reaction forces. The longitudinal train forces, and hence the lateral forces, are dependent on the trailing tonnage.



The lateral force that results from the longitudinal train force acts to redistribute the vertical wheel loads and generates a lateral load on the track. In addition to the train forces, the vertical forces are also influenced by the superelevation of the curve and the train speed. This shift in vertical forces comes about principally due to the inertial forces acting on the center of gravity of the car and to the deflection of the suspension springs.

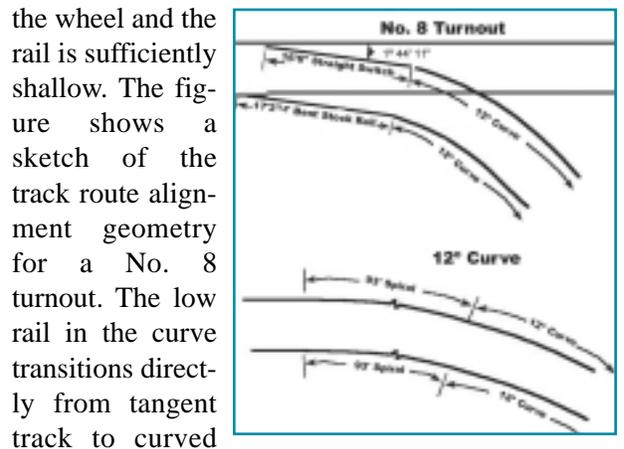
## RESEARCH STATUS

Maximum trailing tonnage was determined as a function of elevation for the unloaded car traversing a 6-degree curve on a 2 percent grade. Results are shown in the figure for two cases, wheel climb and rail rollover for the empty car. The empty car is the most critical car in both cases. Since both wheel climb and rail rollover become likely to occur at critical L/V ratios, the lower the magnitude of the

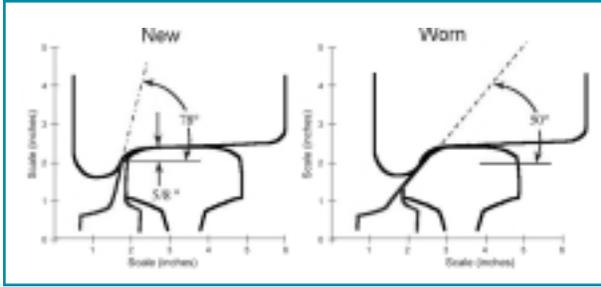


vertical force, the lower the magnitude of the lateral force required to cause the critical condition.

Derailment can occur when a car traverses a switch if there is excessive wear of the gage face of the switch rail. Lateral wheel/rail forces are developed as the car traverses the curvature of the turnout, allowing a wheel to climb the rail if the contact angle between the wheel and the rail is sufficiently shallow.



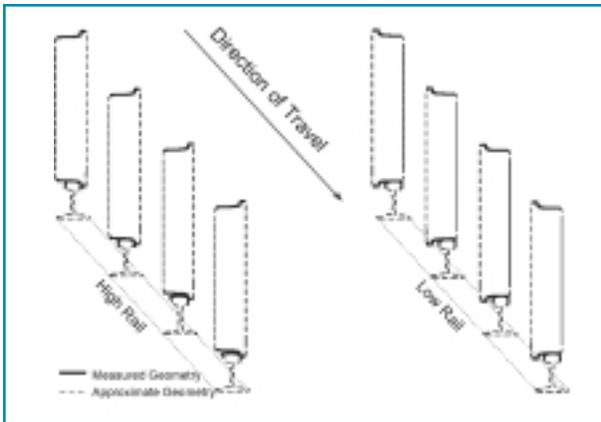
The low rail in the curve transitions directly from tangent track to curved track. The diverging point of the switch curve is essentially tangent for 16.5 feet, with an angle of just less than 2 degrees to the main track. This geometry results in relatively high lateral forces, particularly when the train traverses the diverging route through the switch. For comparison, the AREA recommends a transition spiral length of 93 feet for a 12-degree curve with a revenue service speed of 19 mph. The spiral geometry allows a less sudden transition for the wheelsets.



The figure shows an illustration of the wheel/rail contact geometry, with the rail and the switch point in both the new and worn conditions. As the gage faces of the switch point and rail wear, the contact point moves further down the flange of the wheel. As a result, for the worn condition, the top of the wheel flange contacts the switch point and the side of the rail. When there is significant wear of the gage faces of the switch point and rail, the wheel/rail contact angle is the angle of the gage faces of the switch point and the side of the rail.

### KEY FINDINGS

Preliminary results of geometric analysis of the wheel and rail geometry indicate that changes in rail head profile may allow the wheel to climb the rail.



More detailed analyses are currently being evaluated, including dynamic effects and wheel/rail interaction. Means of extending current models to allow variation of the rail head profile as a function of distance are being investigated.

### FUTURE RESEARCH

Currently, FRA efforts in vehicle/track interaction are primarily directed toward implementing the track surface geometry algorithms in a real-time track surface geometry measurement and evaluation system, experimentally determining the safe limits of track twist, and determining the safe envelope for track gage and alignment geometry. Developing this envelope requires an understanding of how alignment variations can influence rail vehicle response to crosslevel variations. Analytic models are being constructed, exercised, and compared with existing track alignment and gage specifications. The research to be conducted in the next 5 years is expected to include a determination of the safe envelope for gage and track alignment geometry, and a determination of the influence of gage and track alignment variations on vehicle response to profile and crosslevel variations.

# HIGH-SPEED TRACK GEOMETRY SPECIFICATIONS

---

New high-speed equipment standards that cover equipment operating speeds from 110 mph to 200 mph have been developed by the FRA. The incorporation of high-speed operation introduces new requirements on vehicles, geometry standards for gage, surface, and alignment, and the track structure to minimize the potential for unsafe operating conditions. While some standards are identical to their counterparts in lower track classes, several sections are unique to the high-speed environment.

When an encounter with a track geometry variation or series of variations happens at high speed, an unsafe vehicle response such as excessive carbody acceleration or derailment can occur. Large surface variations in track geometry can cause carbody pitch and bounce, resulting in unsafe carbody accelerations or wheel unloading. Track alignment and gage variations can lead to large lateral wheel and axle forces, resulting in derailment or damage to the track structure.

## RESEARCH STATUS

Research has been conducted to identify combinations of surface alignment and gage amplitude and wavelength irregularities that cause excessive accelerations in a vehicle carbody or wheel/rail forces. Locomotive designs have been examined since they could present the largest problem because of their weight. For high-speed operation, locomotives can be designed with traction motors mounted to the carbody or to the truck frame. Both of these potential designs were examined.

A computer model has been developed to determine the minimum amplitude of track surface variation required to cause excessive vertical accelerations (0.6 g) in the locomotive operator's cab. The model has four degrees of freedom (carbody pitch and bounce, and vertical displacements of the front and rear trucks). This model was used to examine locomotives with suspension characteristics and inertial properties representative of those for potential use at high speed. The influence of speed on vehicle response to isolated and repeated track

surface variations was determined for a wide range of wavelengths. The influences of equipment suspension parameters, such as secondary suspension damping, were also determined.

The NUCARS simulation program was used for the analyses of equipment response to track alignment variations. The amplitude of a single perturbation required to cause excessive lateral carbody accelerations, wheelclimb and large wheel rail lateral over vertical forces was determined for a range of wavelengths.

## KEY FINDINGS

The surface analysis results indicate that equipment suspension parameters and configuration strongly influence vehicle response to track geometry variations. In particular, mounting of the traction motors strongly influences vehicle response to track geometry, especially at speeds greater than 125 mph. The analysis results showed that a locomotive design with truck-mounted traction motors requires approximately 33 percent smaller track profile variation amplitude to cause excessive vertical accelerations in the operator's cab than a locomotive design with carbody-mounted traction motors. The results indicate that a locomotive design with truck-mounted traction motors will exceed 0.6 g peak-to-peak acceleration in the operator's cab for isolated 1 inch track profile geometry variations at a speed of 160 mph. These isolated variations range in wavelength from 30 to 100 feet.

The alignment studies indicate that at short wavelengths (less than about 100 feet), the maximum safe amplitude of alignment variation is limited by the wheel rail lateral over vertical forces. At long wavelengths (those greater than 100 feet), safe amplitude of alignment variation is limited by carbody accelerations.

These studies have been used to support the development of high-speed track geometry standards.

## FUTURE RESEARCH

Work in the area of High-Speed Track Geometry Specifications will continue in three specific areas. First is the continued mapping of vehicle response to geometry variations and combinations of variations. Also important in this area is the treatment of innovative truck, car, and trainset designs, including passive, frequency tuned and fully active steering and suspension elements and articulated vehicle connections. Second is the detailed investiga-

tion of the influence of specific wheel and rail profiles and the importance of controlling the contact geometry, especially in proximity to special track features such as turnouts. Finally, studies will be conducted to determine how best to focus inspection technologies to identify incipient track geometry conditions before reaching safety critical amplitudes. An important aspect of this research is to develop a comprehensive strategy for assuring adequate geometry.

# INTELLIGENT TRACK/TRAIN SYSTEMS





## POSITIVE TRAIN CONTROL DEVELOPMENT

---

### SUMMARY

Work at the FRA during the past 5 years relative to Positive Train Control (PTC) systems has centered on the potential safety issues and benefits involving the implementation of new, highly-automated systems. Initiatives described elsewhere in this R&D summary that are related to PTC implementation include human factors and automation, knowledge display interfaces, highway-grade crossing and train control system linkage, and the validation and verification of microprocessor controlled systems. In addition, the aspects of PTC that relate to system operational enhancements and equivalent safety assurance at higher speeds are covered in portions of the Next Generation High Speed Rail Program description.

Starting in 1982, the Association of American Railroads (AAR) and the Railway Association of Canada (RAC), initiated a project called Advanced Train Control Systems (ATCS). During the next 10 years, the AAR and the RAC worked with their system engineering contractor, ARINC Research Corporation, to develop a set of specifications for functions of an ATCS.

The goal of ATCS was to develop a series of comprehensive and advanced operating systems based on the use of real-time communications, and information or data processing for the control of train movement. Such control was considered essential for improving safety, productivity, service quality, and the energy efficiency of railroads.

In 1984, the Burlington Northern Railroad (BN) and Rockwell International agreed to work together on an ATCS-type system to integrate control, communications, and information in the railroad environment. The system came to be known as the Advanced Railroad Electronics System (ARES).<sup>1</sup> By 1987, an operating system was under testing on the Minnesota Iron Range. The prototype testing lasted for over 5 years on 250 miles of track and while considered a technical success, it was terminated along with the ATCS program in 1993.

The ATCS specifications were based on six functional goals, including presence detection, train and locomotive identification, track and route integrity, ancillary systems interface, switch control, and train control and management. The specifications were highly developed, and a preliminary version of these was published in 1992. Some of the ATCS standards, such as communication protocols, were already in everyday use by a number of railroads when the AAR formally terminated the ATCS effort in 1993.<sup>1</sup>

Since 1993, new terms such as Positive Train Control (PTC) - which encompasses a variety of potential train control, management, and operations automation tools - and Positive Train Separation (PTS) - which relates solely to a safety enforcement system - are used when advanced train control systems are discussed. Some terms are generic and some are system specific. The key basic building blocks of PTC systems revolve around two functions, however, safety assurance and system operational efficiency. In essence, these basics follow the goals and objectives of the ATCS initiative. Yet, with the loss of the ATCS initiative, the effort to work toward common standards and achieve interoperability of the PTC systems under development, has become more difficult.

An adequate base of technical expertise will be maintained in the areas of accurate position location technologies such as the Global Positioning System (GPS) and Differential Global Positioning System (DGPS), digital radio communications, and remote control and sensing. Given the large number of PTC initiatives currently underway as listed in the accompanying table, the major emphasis for the next 5 years will be to ensure that lessons learned from the various projects are applied to the other projects as appropriate. More details on these specific initiatives can be found in the Next Generation High Speed Rail section of this report.

PTC INITIATIVES		
Title	Proponent(s)	Supplier
Pacific Northwest PTS	BNSF, UP	GE-Harris
Michigan ITCS	FRA, State of Michigan, Amtrak	Harmon Industries
Illinois PTC	FRA, State of Illinois, AAR	TBD
PTC On-Board Locomotive Communications Bus	CR/NS/CSX	Rockwell
Long Island Intermodal Control System	FHWA, State of New York, LIRR	Alstom
Advanced Civil Speed Enforcement System (ACSES)	Amtrak	Alstom
Alaska Railroad RTC	Alaska RR, FRA	GE-Harris
CSX Communications-Based Train Management System (CBTM)	CSX	Rockwell
Enhanced Proximity Warning System (EPWS)	BNSF	Pulse

Safety issues relating to the various approaches will be addressed, ranging from overlay systems, to simple enforcement systems, to highly-automated advanced control systems. In addition, other safety issues will be covered including interoperability (or the lack thereof), and specific technology designs such as safety-critical communication links and location determination, including both DGPS- and transponder-based methods.

Given the wide variety of suppliers involved, a major effort will be made to avoid the development of systems that inhibit interoperability and the resultant economies of scale of PTC implementation. The European Community initiatives, the European Radio and Traffic Management Systems (ERTMS) and the European Train Control System (ETCS), will provide useful information about how one group meets extensive interoperability issues.

The conversion of the US Air Force Ground Wave Emergency Network (GWEN) System to supply nationwide DGPS signals that meet Coast Guard protocol, for the use of communication-based train control systems, will be supported with technical expertise to assure adequate signal coverage and the mitigation of potential electromagnetic interferences to the signal from external sources and railroad operations.

**Conrail/CSX/Norfolk Southern Positive Train Control** - This was originally a train control project for development by Conrail. Given the acquisition of Conrail by CSX and the Norfolk Southern (NS) Railroad, the project has evolved into a joint venture between all three railroads. The proposed train control test segment is Conrail’s Harrisburg, Pennsylvania to Manassas, Virginia line. Conrail/CSX/NS have chosen Rockwell Transportation to develop the onboard locomotive communication platform. The system will comprise a data bus encompassing train position, communications, and brake application capabilities for multiple train control systems from dark territory to in-cab signaling systems. The data bus will be open architecture, therefore precluding the railroads from being constrained to a single supplier. The data bus will be capable of interfacing with GPS receivers, wheel tachometers, electronically-controlled pneumatic (ECP) braking systems, or cab signals.

**Communications-Based Train Control Enabling Technologies** - The components employed in CBTC systems include wireless communications networks, digital navigation systems, locomotive onboard communication platforms, and computer-aided dispatching (CAD) systems. Although the functions do not vary significantly, the implementation of these systems varies depending on the sup-

plier and the application. A brief discussion of the enabling technologies for these systems follows.

**Wireless Communication Systems** - Railroads and suppliers are testing the feasibility of various communication systems for broadcasting train control data. These systems include spread spectrum radio and conventional VHF and UHF radio. Also, the reframing of the frequency spectrum for narrowband radio by the FCC will provide railroads and transit agencies with access to almost twice as many licensed channels as are currently in use. These changes are currently being evaluated by railroad operations so as to optimize their use of the spectrum.

Spread spectrum radio communication networks have key advantages in that they do not require FCC licensing to be deployed, offer large amounts of bandwidth, are highly reliable, and are relatively inexpensive to procure. The Amtrak ITCS program in Michigan employs a spread spectrum radio network as the backbone of its wayside communication system. Also, the BART AATC demonstration program in San Francisco is employing a highly sophisticated spread spectrum radio-based-communication system. The radio system, the Enhanced Position Location and Reporting System (EPLRS), was developed by Hughes aircraft for the United States Army. In the State of Washington's PTS program, BNSF and UP are using frequencies from their existing UHF radio system to transmit data such as movement authorities, speed limits, and track warrants to test locomotives. Although these frequencies do not have the channel capacity of spread spectrum systems, they are specifically licensed to the railroads by the FCC and operate on an already existing system. Conrail, NS, and CSX are studying the feasibility of using their existing VHF radio networks as a data link on the PTC system they are jointly developing in Pennsylvania and Virginia.

**Navigation Systems** - Suppliers are developing navigation systems that employ highly sophisticated technologies such as GPS and DGPS and ground-based radio ranging technologies for highly accurate position resolution. GPS, a high availability Air Force satellite positioning system, is being tested in several pilot train control projects throughout the country. To facilitate the BNSF/UP project in Washington, the FRA worked with the U.S. Coast

Guard to convert a retired Air Force Ground Wave Emergency Network site into a high-power DGPS site in Appleton, Washington, that functions as part of the United States Coast Guard beacon system. This site provides 2-meter location resolution and is the prototype site for a nationwide DGPS network.

#### **Locomotive Onboard Communication Platforms**

The locomotive onboard computer systems, in addition to performing functions as train overspeed protection, are required to communicate with locomotive propulsion systems and electronically controlled pneumatic braking systems, and monitor locomotive health. The key element of onboard communications is the networking protocol linking the components. Several industry protocols that have been the subject of recent evaluation are Lonworks IEEE 1473.1, Ethernet IEEE 802.3, and Token Ring IEEE 802.5. The Conrail, NS, and CSX design team has recently chosen Lonworks IEEE 1473.1 as the onboard platform protocol in their recently released design. This protocol was chosen based on its reliability, availability, and maintainability characteristics. This is a significant step forward in the industry-wide effort for an open architecture, interoperable protocol given that Lonworks IEEE 1473.1 is employed in many of the ECP systems currently under test.

Specific advanced train communications and control activities have included:

- An assessment of potential modifications to 49 CFR Part 236 (Railroad Signaling Systems) to better accommodate microprocessor interlocking technology;
- A two-volume report on validation and verification methodologies for safety critical control system (see Section 9 for more details).

<sup>1</sup> *Advanced Train Control Systems 1991, Transportation Research Record No. 1314 Rail, Proceedings of a Symposium, Transportation Research Board, pages vii and 50.*

## CORRIDOR RISK ASSESSMENT MODEL

---

The FRA seeks the ability to refine evaluations of safety risks on rail corridors. This model will help assess the safety implications of various signal and train control systems and other safety systems on the intercity railroad network and on specific railroad corridors.

### RESEARCH STATUS

The report to Congress in July 1994, from the FRA, Office of Safety, entitled *Railroad Communications and Train Control*, found that nationwide application of higher level train control systems that could avert certain types of serious train accidents was not economically justifiable solely from a safety perspective. The FRA initiated the development of an analytical model that would identify a class of corridor for which signal and train control systems might prove useful. In 1995, the Volpe Center began a corridor risk assessment model (CRAM) study for the FRA. The objective of this study was to develop a tool capable of analyzing the potential risk reduction for specific railroad corridors, if equipped with higher level train control systems that can exercise positive train control (PTC).

Freight lines/corridors of a wide variety of configurations were identified. The FRA's geographic information system (GIS) was utilized as a platform in corridor identification. In addition to the development of a risk exposure algorithm for the model, the capabilities of the GIS data base were augmented to support the location accuracy and data depth needed for this specific model.

### KEY FINDINGS

Risk factors defining safety risk for high-density freight/passenger corridors were identified. These factors included, but were not limited to the number and type of trains (freight or passenger) operating in the corridor, the relative speed of trains on the line, whether or not hazardous materials are transported in the corridor, the traffic density of these materials, the number of grade crossings, and the type of existing signal and train control systems.

### FUTURE RESEARCH

This study will result in an analytical model capable of using historical accident data, track configuration (number of tracks, type of signal system), topography, population densities, existing passenger and freight densities and types to determine the potential risk impacts of various types of train control systems from dark (no signals) to full positive train control implementation.

The enhanced GIS data base resulting from this work will also be useful in a wide variety of railroad network safety analyses. Accident and incident information will be geo-located on the GIS platform on a yearly basis as the data become available.

# POTENTIAL BUSINESS BENEFITS OF ADVANCED TRAIN CONTROL SYSTEMS

## POTENTIAL BUSINESS BENEFITS OF ADVANCED TRAIN CONTROL SYSTEMS

In addition to documenting the safety enhancements possible as a result of applications of advanced train control systems on the U.S. intercity railroad system, the FRA also needs to better understand the potential business benefits of such systems. This work seeks to refine the state of knowledge regarding the operational impacts that advanced train control systems, such as positive train control (PTC), can have on operational corridors or regions of major Class I railroads.

In 1997, the Railroad Safety Advisory Committee (RSAC) accepted a charge to pursue issues surrounding implementation and safety assurance of PTC-type systems. A working group to address PTC issues was formed. As part of this collaborative effort, the FRA has generated information for the use of the RSAC PTC Working Group and for the agency to have as a foundation to support any necessary economic regulatory analyses that may be necessary in the future.

### RESEARCH STATUS

In December of 1997, a draft of the report “*An Examination of the Costs and Business Benefits of Positive Train Control*” was completed for the FRA by Parsons, Brinckerhoff, Quade and Douglas, and Zeta-Tech Associates, Incorporated. This draft was distributed to the RSAC PTC Working Group for their review, comment and guidance.

The purpose of the study was to provide a preliminary estimate of the business benefits of PTC. Five short railroad corridors, similar to the corridors studied in the corridor risk assessment analysis, and representing a range of conditions, were selected for study of the business benefits that would accrue if PTC were applied to each corridor. Benefits were quantified in the following areas:

- reduced yard and transit time from improved work order reporting;
- reduced maintenance hours and en-route

- failures from locomotive diagnostics fuel savings;
- reduced cost from improved equipment utilization;
- higher revenue from improved customer service.

Benefits due to improved equipment utilization and customer service accounted for approximately 45% of estimated benefits; benefits from fuel savings and locomotive diagnostics, another 47%; and the remaining 8% was due to work order reporting.

### KEY FINDINGS

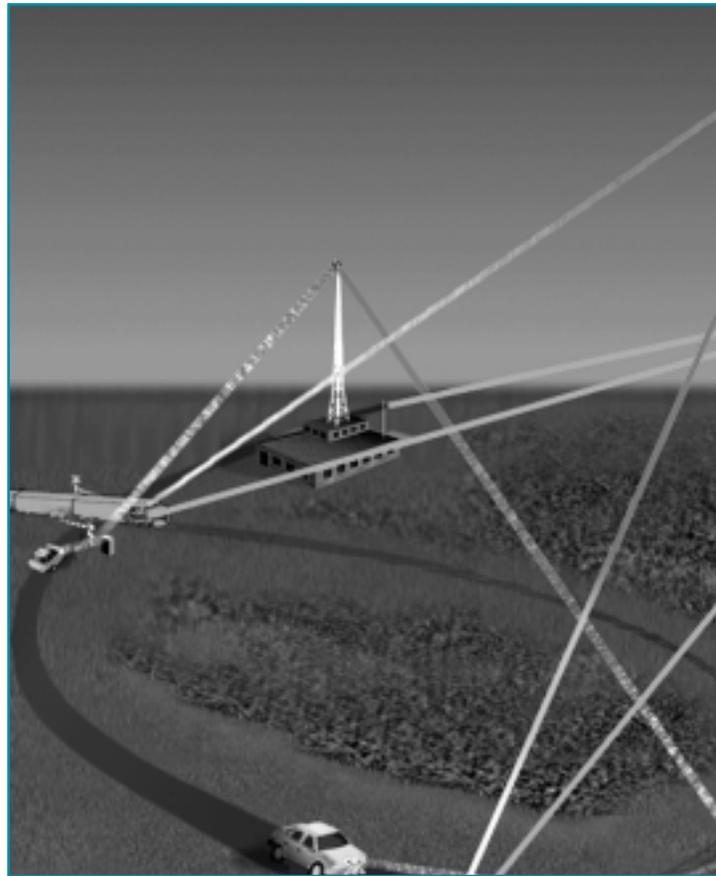
Benefits quantified on the short corridors in this study (safety benefits were not included) were enough to cover 40% to 90% of total capital and operating cost of PTC, depending on the corridor and on the assumption regarding the number of locomotives that must be equipped. It is likely that cost coverage would be considerably higher if longer corridors that conform more closely to major transportation markets were chosen for analysis, and if other business benefits not quantified in this study were able to be quantified. This is true not only because of the additional benefits, but also because as more PTC-equipped route miles are added, fewer additional locomotives need to be equipped per added mile.

### FUTURE RESEARCH

As the various PTC initiatives in the U.S. progress, more real world data will be available for updating this study’s findings. In addition, the scope of the business benefits will clearly expand in the future as PTC is more widely accepted and therefore has more significant impacts on system operational methods and results. Finally, this work will be combined with the corridor risk assessment model results discussed in the previous section, and with other related work, to allow a full appreciation of the full benefit/cost impacts that PTC system implementations could have on major U.S. intercity rail lines.



# HIGHWAY-RAIL GRADE CROSSING SAFETY



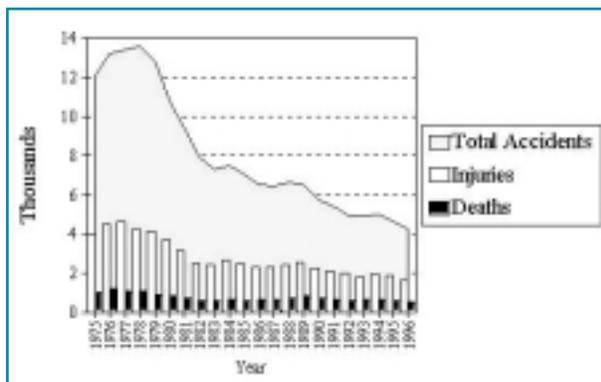


## HIGHWAY-RAIL GRADE CROSSING SAFETY

### SUMMARY

Grade crossings present a major hazard to motor vehicle drivers and are the greatest cause of fatalities and injuries resulting from railroad operations. With the advent of proposed high-speed rail passenger trains, grade crossings also may pose a significant risk to rail passengers. In 1995, there were a total of 4,633 accidents at both public and private crossings, resulting in 579 fatalities and 1,894 injuries. Significant progress has been made in improving the safety of public grade crossings as shown in the figure below. From 1978 to 1993, wide ranging, multi-disciplinary safety improvement efforts of the FRA, in partnership with other agencies and industry groups, resulted in a 64-percent reduction in the number of grade crossing accidents.

There are many different causes of these accidents. However, the majority of accidents involve elements of driver behavior such as inability to recognize the crossing as a risk or taking inappropriate actions in spite of recognizing the risk. For example, the majority of accidents at passive grade crossings involved motorists not stopping. In addition, 15 percent of accidents at gated crossings involve automobiles where the motorists drove around lowered gates. Determining why such errors in driver behavior take place and identifying means to improve safe driving behavior is being examined through several research projects.



Yearly Grade Crossing Incidents

To ensure that a comprehensive set of initiatives are pursued in improving grade crossing safety, the FRA, in an interagency effort with National Highway Traffic Safety Administration, Federal Highway Administration, and Federal Transit Administration, prepared the U.S. DOT's *Highway-Rail Crossing Safety Action Plan*, released in June 1994. The goal of the *Action Plan* is to achieve at least a 50-percent reduction in collisions and fatalities by 2002. The Action Plan identified six areas of effort and 55 safety initiatives at the Federal, state, and local level. It also proposed a number of activities including a workshop to develop an intermodal consensus on projected research needs to support continued improvements in highway-rail crossing safety. The Highway-Railroad Grade Crossing Safety Research Needs Workshop was conducted from April 10-13, 1995, by the Volpe Center. In the *Safety of Highway-Railroad Grade Crossings: Railroad Horn Systems Research - Volume I*, July 1993, 92 research needs were identified and published. Many of the current and planned research projects described herein were identified at the Workshop.

The Grade Crossing Safety Task Force was formed by the Secretary of Transportation following an accident involving a school bus and commuter train at Fox River Grove, Illinois. This Task Force was to examine the causes of this accident and to evaluate the decision-making process related to making improvements at grade crossings. The Task Force report, *Accidents That Shouldn't Happen*, is a supplement to the *Action Plan* that focuses on the planning, construction, maintenance, operation, and inspection activities involving grade crossings. The Task Force concentrated on interconnected highway traffic signal and highway-rail crossing warning devices, available storage space for motor vehicles at those crossings, high-profile crossings and low-clearance vehicles, light rail transit crossings, and special vehicle operating permits and information. A report on the progress of the Working Group was published in June 1997.

The FRA will continue to perform various activities to ensure that research results are successfully deployed. Appropriate documentation and dissemination of results will be performed. Seminars, workshops, focus groups, and conferences will be conducted to assist in the deployment of results to intended users and to identify more effective means of deployment. Technical guidelines will be prepared and technical support will be provided, as needed, to assist in the use and implementation of research results.

The objectives of the FRA Grade Crossing Program are to improve grade crossing safety through research in the following areas:

- **Driver Behavior** - improve knowledge of driver behavior and means to promote safe driving behavior through education and enforcement;

- **Driver Warning Systems** - improve driver warning systems, both visual and audible;
- **High-Speed Rail Grade Crossings** - develop means of reducing the risks at high-speed train crossings; and
- **Intelligent Transportation System (ITS) Concepts** - evaluate ITS concepts for improving grade crossing safety.

## DRIVER BEHAVIOR

---

**Driver Behavior at Grade Crossings** - The Research Needs Workshop suggested that more needs to be known about why motorists take risks at grade crossings (e.g., driving around gates directly in front of trains). Such risk taking may be correlated with demographic or socio-cultural variables and may be influenced by train speed, perceived distance, warning times (for active devices), sight distance, and driver familiarity with the grade crossings. Motorists' perception of risk may be determined by the perceived frequency of trains, and decisions to cross or stop may be critically influenced by perceived costs (including fines for noncompliance) and benefits associated with each action. In the absence of better information concerning the determinants of risky behavior, efforts to ameliorate or change the behavior will be ineffective. This project will attempt to identify the major variables which cause risky behavior so that a systematic effort to enhance safety can be undertaken.

In support of this research, a low fidelity driving simulator is being developed to study driver behavior issues at grade crossings. The grade crossing simulator is part of the train simulator at the Center for Human Factors in Transportation at the Volpe Center. The Massachusetts Institute of Technology (MIT) has developed the software which displays rail cars on the simulator and will provide software to simulate moving passenger vehicles as well. The driver behavior project will address a variety of issues concerning the behavior of motorists at grade crossings.

**Driver Education Programs** - Operation Lifesaver, Inc. (OLI) is a nationwide non-profit organization which provides public information and education dedicated to reducing accidents, injuries and fatalities at grade crossings. In 1996, the FRA worked with OLI to conduct a series of focus groups to determine how specific target groups perceive grade crossings, evaluate that perception, and develop an effective message to educate those tar-

get groups. The FRA is also represented on the committee that plans OLI activities each year, and is one of several public and private agencies that sponsor OLI activities.

The Research Needs Workshop identified several high priority research needs in the area of driver education. These included determining target audiences, survey of current and completed research, survey of existing programs, funding sources, and program evaluations (OLI, driver education, crossing safety media, and trespassing media).

Defining the target audience for an educational program not only improves the efficiency of message delivery, but allows the message to be optimally structured to reach its intended audience. A survey of current and completed research will avoid duplication of effort and help to identify innovative efforts. A survey of existing programs (media, print, video, radio, etc.) will avoid duplication of effort and may identify potential partnerships. A survey of funding sources will identify potential alternate funding sources in the public and private sectors. Program evaluations will identify effective approaches and programs for the limited available resources.

**Causal Analysis of Grade Crossing Accidents** - In this effort, the FRA will combine an analysis of grade crossing accident data with human factors studies to develop a causal model of driver behavior at highway-railroad grade crossings. The model will address information needs and decision-making processes of drivers at both active and passive crossings. This investigation will identify safe and unsafe (risk taking) behaviors of drivers at crossings under these varying conditions. This model then can be used to assist in identifying more effective countermeasures to avoid collisions at crossings.

In addition to the driver behavior model, a behavioral "postmortem" of grade crossing accidents can reveal information concerning driver motivation, state-of-mind, behavioral patterns, and demograph-

ics that may influence accident causation. Such information will be gathered by interviews with friends, family, and witnesses in fatal accidents. For non-fatal accidents, drivers and witnesses will be interviewed. The information obtained will help in identifying effective countermeasures such as targeting audiences for safety programs and for tailoring messages to specific groups.

**Signal Detection Theory Analysis** - This approach to the analysis of driver behavior considers safe driving at grade crossings to be the natural outcome of proper human information processing and decision-making. At a grade crossing, a driver uses sensory information from the train (a signal which consists of visual, auditory, tactile, and olfactory elements) and the area surrounding the crossing (background noise) to judge the proximity or position of the train. The driver must decide, based on the sensory information, whether or not it is safe to drive through the crossing. Analysis results should be useful in predicting accident rates based on the physical characteristics of trains and crossings, and human sensory, perceptual and cognitive characteristics including attention, motivation, expectation, and memory.

**Post-Accident Train Crew Behavior** - An important area of research is the need to identify problems and solutions to the effects of grade crossing accidents on train crew behavior. During the course of a locomotive engineer's career, it is likely that he or she will experience a traumatic grade crossing accident. It is sometimes the case that, after a grade crossing accident in which the train crew is unhurt, the crew continues to operate the train. The possible psychological trauma suffered by the train crew and its potential long-term effects on their continued safe performance is not well understood. This task would investigate these issues and develop suggestions for remedial actions.

**Improved Credibility and Warning Time of Active Devices** - The Research Needs Workshop identified improving the credibility of active warning devices as a key issue. Related to this is the need to optimize the warning time for the motorist to minimize delays yet maintain safety under a variety of train and highway vehicle operational conditions. Grade crossing warning devices should provide the same, safe warning time to drivers regardless of train speed. However, many older devices may provide only a fixed warning time which may be too short if not properly calibrated for changes in train speeds.

**Data Requirements for Crossing Safety** - Current highway-rail grade crossing information is fragmented into many different data bases that are located in various organizations. Collection of data is not coordinated, and the public and private organizations that use the data have diverse needs. New technology offers the potential for more broad-based and cost-effective data collection and management. This project would identify the data requirements for a broad range of safety studies and evaluate current data elements and data collection and management systems. New data collection, storage, and retrieval technologies will be evaluated and recommendations for changing current practices will be developed.

**Photo Enforcement** - Photo enforcement holds significant potential for achieving greater compliance by motorists of safety laws at crossings. Several research issues are related to wider use and effectiveness of photo enforcement including applicable technologies, driver behavior, and legal/legislative impediments. The FRA will continue to monitor and assess photo enforcement demonstration projects and research. In particular, the Los Angeles Metropolitan Transit Authority photo enforcement project on the Blue Line will be evaluated.

## DRIVER WARNING SYSTEMS

**Locomotive Conspicuity** - In response to the requirements of alerting-light legislation in 1992, the FRA initiated a review of current and innovative techniques and designs to improve the visibility of locomotives to motorists, including the use of strobe lights, crossing lights, ditch lights, paint schemes, improved headlights, front-end illumination, and retroreflective materials.

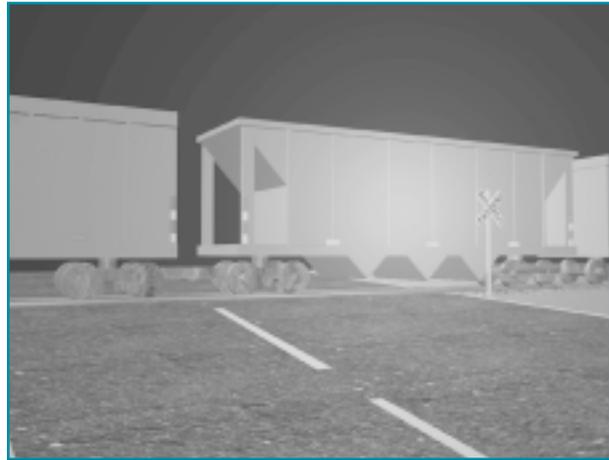


### Locomotive Alerting Lights

This study was completed and published in 1996. Continued research was performed in 1997 to resolve technical issues that arose during the locomotive conspicuity rulemaking efforts, and to provide additional technical documentation and presentation of research results. The FRA will also monitor the 3-year study, beginning in 1997, on flashing versus steady alerting lights being conducted by the AAR.

**Freight Car Reflectorization** - Over the past decade, innovations in the manufacture of retroreflective materials have resulted in their increased brightness and durability. These improvements have prompted additional research to determine if these new materials can provide cost-effective enhancements to freight car visibility. This research has included a literature review, a demonstration test at

the Transportation Test Center, in-service field tests, and human factors tests under controlled laboratory conditions. Data from these research activities have been analyzed, and documented in a final draft report currently under review by the FRA. The Volpe Center, Alaska Railroad, Norfolk Southern Corporation, and University of Tennessee at Knoxville have contributed to this research effort.



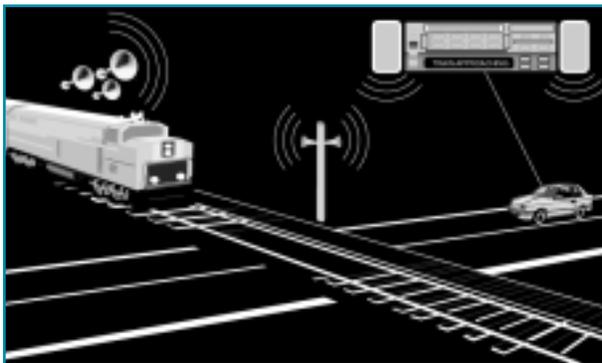
### Freight Car Reflectorization

Research to examine motorists' responses to reflectorized rolling stock is currently being performed. This research includes participation by the Department of Mechanical Engineering of the MIT. This effort involves the observation by subjects, under controlled laboratory conditions, of various configurations of prismatic retroreflective materials. The observations are made using a driving simulator that reproduces realistic dynamic scenarios of moving freight cars and motor vehicles. Results of the tests will show which combination of reflector patterns and colors produce the best driver response.

**Acoustic Characteristics of Railroad Horn Systems** - This research effort was performed to determine the acoustic characteristics of several types of railroad horn systems. The effort involved the measurement of horn acoustic characteristics at selected nationwide sites. Data obtained include

frequency spectrum, direction of sound, drop-off rate, maximum A-weighted sound level, and sound exposure level. The results of this study are presented in the report, *Safety of Highway-Railroad Grade Crossings: Study of Acoustic Characteristics of Railroad Horn Systems*.

**Effectiveness of Railroad Horn Systems** - This research is aimed at determining the effectiveness of railroad horn systems in warning motor vehicle drivers and the resulting noise impacts on the community. Acoustic data were obtained for a horn system through wayside measurements of in-service locomotives to determine acoustic intensity at the roadway and the community noise exposure. The loss of acoustic intensity between the exterior and interior of motor vehicles (insertion loss) and interior noise levels of motor vehicles were measured. These results were then used to determine if the warning signals created by railroad horn systems were sufficient to provide effective warning to the motorist under various crossing conditions. The resulting community noise impacts were also determined for different numbers of daytime and nighttime trains. The results of this study are presented in a report, *Safety of Highway-Railroad Grade Crossings: Railroad Horn Systems Research - Volume II*, scheduled for publication in FY1999.



#### Railroad Horn System

**Field Evaluation of a Wayside Horn** - This research evaluates the effectiveness of an innovative auditory warning device installed at the crossing referred to as a stationary horn or wayside horn. In concept, by placing the acoustic warning device at the crossing rather than on the train, the ability to warn motorists of an approaching train may be enhanced while community noise impacts may be

reduced compared to a train horn. The effort involved two surveys comparing the community noise impact of a wayside horn to a train horn, and an analysis of motorist behavior in response to the two types of horn at the grade crossing. Acoustic data were collected to describe the sound characteristics of each warning signal. Implementation issues that will impact safety and community noise for the wayside horn were also identified. These issues include activation method, hardware design, and standardization. The results of this study are presented in a report, *Safety of Highway-Railroad Grade Crossings: Field Evaluation of a Wayside Horn*, scheduled for release in 1998.

**Optimal Acoustic Warning Systems** - Audible devices such as train horns have long been used to provide warnings to motorists and pedestrians of an approaching train at grade crossings. This research activity will investigate means of improving the effectiveness of train horns and other audible warning devices. One method of increasing the effectiveness of audible warning devices is to increase their sound pressure level (SPL), but the increased SPL can result in unacceptable noise impacts on surrounding communities and locomotive train crews. An alternative approach is to change the spectral content, duration, and/or repetition rate of the signal. Related studies have concluded that this approach may result in an increase in drivers' perception of the audible warning. The objective of this project is to determine the optimum performance characteristics of audible grade crossing warning systems in terms of sound pressure level, frequency and repetition rate, while minimizing community noise impact. This information will be integrated to develop the functional specifications for an optimal acoustic signal for motor vehicle drivers to prevent grade crossing accidents. This research is scheduled to begin in mid-1998.

**Innovative Barrier Systems** - Barrier systems have been used at grade crossings as a means of physically preventing motorists from entering the crossing. The traditional gate system blocks the entrance lane to the crossing when a train approaches. While this device is highly effective, it has several shortcomings. Since it only blocks the entrance lane of the roadway, drivers can drive around the gate. Furthermore, the gate is not an impenetrable

barrier and drivers can unintentionally drive through it. Several innovative barrier systems have been proposed for various grade crossing applications to improve upon the traditional gate system. Mobile (or movable) barriers can be used to close certain crossings temporarily in conjunction with nighttime whistle bans, and high-speed rail crossing barriers can be used to block the full roadway width at crossings over which high-speed passenger trains travel. For all three barrier systems, a crucial aspect for their ultimate success is driver acceptance. Traffic delays caused by the use of standard gates are known to frustrate drivers and result in driving around the gates. While driving around behavior cannot occur at mobile barriers and high-speed rail barriers, non-acceptance likely will result in public pressure to remove the barriers, or impede their implementation. Research on these devices will focus on determining factors that affect driver acceptance (duration of delay, perceived risk, demography of local population, etc.). Procedures will be developed for use in evaluating the effectiveness and driver acceptance of innovative barrier systems that are tested as part of public demonstrations.

**Commuter Crossing Safety** - Commuter rail operations occur over the most heavily used corridors of the nation with highway-rail grade crossings frequently occurring at less than 1-mile intervals and at times when highway traffic is at its daily peak. Unfortunately, this maximizes the likelihood of incidents occurring and the severity of their consequences. Research in this area will focus on driver decision-making at rail-highway crossings involving commuter scenarios. Assessments will be made of advanced protection systems making use of in-place infrastructures such as adjacent traffic control devices and urban highway traffic control centers.

**Illumination Guidelines** - Accidents that involve motor vehicles running into trains are known as RIT collisions. In 1995, on U.S. public grade crossings without active warning devices, the ratio of RIT collisions to train-into-motor vehicle collisions was much higher during non-daytime operations, i.e., after dark, at dusk, or at dawn, than during daytime hours. More than one-third (271) of the 791 non-daytime accidents were RIT collisions, whereas less than one-fifth (238) of the 1,252 daytime

accidents were RIT collisions. Accordingly, the FRA is investigating illumination systems for enhancing the visibility of crossings and trains with the support of the Oregon Public Utilities Commission and the Burlington Northern Railroad. Relevant literature was reviewed regarding standards and practices of grade crossing illumination, data on existing illumination installations were collected and analyzed, sample recommended illumination designs were developed, and the results are being documented. The documentation, expected to be finalized in 1998, will be in the form of an installation guideline report and a guideline pamphlet summarizing the recommended practices.

Future illumination research may involve human response studies to establish the optimal values of illumination at grade crossings. These tests will determine the probability of detection (recognition) of freight cars under different lighting conditions. This effort would also include measurement of the optical reflectivity on a representative sample of railroad freight cars to determine the light intensity needed to provide motorists with sufficient warning to stop safely.

**Active Warning Device Failure Analysis** - The FRA enacted reporting rules for active grade crossing signals under 49 Code of Federal Regulations (CFR) Part 234. The FRA has analyzed signal system failure reports submitted by the railroads as required in Part 234.9; as well as information required by Part 234.11, inspection, testing, and maintenance procedures; and Part 234.13, active signal circuit and component information. The effort included review and analysis of all information provided by the railroads under this reporting requirement. The purpose of the analysis was to identify the various circuit types and failure modes as well as to determine the need for the establishment of enhanced regulatory procedures to maintain, inspect, and test all active warning systems at highway-railroad grade crossings. During the conduct of the effort, the FRA developed a final rule for inspection, testing and maintenance of active signal systems. A final draft report documenting this research was completed in 1996 and is now under review by the FRA. Using the data bases and the analysis plan developed under this effort, further analyses will be performed to determine options for

reducing false activations and activation failures.

**Assessment of Passive Systems** - The FRA is developing requirements for conducting field studies of innovative passive signs for use at grade crossings. Studies in progress that the FRA is assessing include human response research being conducted by the Federal Highway Administration, Texas Agriculture & Mining University, the University of Virginia, and Kansas State University. The FRA also is assessing the “Buckeye Shield” crossbuck in coordination with the Ohio Department of Transportation (ODOT). An evaluation plan for ODOT has been developed by Ohio State University for conducting near-collision studies along corridors in Ohio where the Buckeye Shield will be installed.

The FRA will develop generic requirements for field testing of innovative passive signs, to include engineering criteria for grade crossing site selection, measures of effectiveness, data collection and reduction techniques, and reporting criteria. Engineering support for conducting and documenting such field tests will be provided to local agencies.

**National Warrants for Grade Crossing Warning Devices** - The Research Needs Workshop identified as a key issue the need for national warrants and/or guidelines for the use of warning devices at crossings. Such warrants could potentially replace the current system where the decision for selecting specific applications at crossings rests primarily at the state level and local level. If national warrants were implemented, the impact on liability issues resulting from grade crossing accidents could be significantly minimized. This task will be initiated in 1998. Research issues would involve a preliminary definition of the content of these warrants and their potential impacts on the warning device selection process and on safety liability.

**Assessment of Highway Signals at Grade Crossings** - The Research Needs Workshop identified the potential application of standard highway traffic signals at crossings as a key issue. Because of the ubiquitous nature and easy recognition by motorists of standard highway traffic signals, their application at crossings could significantly enhance safe driving behavior by motorists. Research issues could involve investigations of the human response

to the application of standard traffic signals at grade crossings and the technological and legal implications of these devices at crossings. This research effort will be coordinated with Federal Highway Administration.

**Low Cost Alternatives to Conventional Warning Devices** - Two-thirds of grade crossings are equipped with passive devices and, although exposed to only approximately ten percent of the traffic, they account for almost half of the accidents at grade crossings. Resources are not available to equip the majority of these crossings with active devices such as flashing lights and gates. Research in this area will examine the effectiveness of alternative low-cost systems that may be used at low density crossings which would warn motorists of an approaching train or a train occupying the crossing. Systems to be investigated will include those that only detect trains occupying crossings at night and those designed to be reliable but not necessarily fail-safe. The research will also include estimation of the costs and risk reduction benefits of alternative systems.

**Loss of Shunt** - Most grade crossing detection systems rely on a train’s ability to shunt electrical current from one rail to the other as a means of train detection. Both the railroad signal community and the grade crossing equipment suppliers have reported an increase in the occurrences of loss of shunting on railroad grade crossing island circuits. Loss of shunt can result in failures of the warning devices to activate or to activate intermittently. Such failures can significantly undermine safety at grade crossings. To address the loss of shunt (LOS) problem, the Track Circuit Parameters Task Force was formed in August 1993. Funded by the FRA, the AAR/TTCI conducted a study of the LOS problem. In the initial phase of the program, data on shunt activations, weather, climate factors, and rail surface condition were collected over a 6-month period from eight field locations throughout North America. Statistical analysis of these data indicated that occurrences of LOS severe enough to release an island relay were rare, occurring in approximately 46 out of every 10,000 shunt events.

In the second phase of this investigation, an attempt was made to replicate LOS in the laboratory. The AAR’s railroad wheel dynamometer was used to

simulate the rail-wheel interface. This laboratory testing allowed for the controlled application of loads, brakes, etc. Rail surface film samples taken from the laboratory tests differed from those taken in the field; LOS occurred sporadically in the laboratory, with little ability to control or repeat.



Railroad Wheel Dynamometer at AAR

In the third phase of testing, an attempt was made to determine the pressure-resistance relationship between wheel and rail. Laboratory testing revealed a distinct relationship between contact pressure and resistance. Field results also indicate that heavier cars are less likely to cause a LOS.

Results of the testing indicate that surface films on rails and wheels are major contributors to the LOS problem, but research revealed no promising mitigation techniques to reduce or eliminate this problem.

**Train Presence Detection Study** - This study evolved from the LOS study, completed in 1997, and examined causes where a grade crossing warning system would lose continuity of train detection, which can give rise to intermittent shutdown of crossing warning devices while the train is in the crossing. A joint FRA/AAR effort, testing of shunt performance at seven sites as well as at the TTC, has been completed. Further FRA/AAR efforts in 1998 and 1999 will test new train detection devices at TTC.

## HIGH-SPEED RAIL GRADE CROSSINGS

---

**Intrusion/Obstruction Detection** - Intrusion detection systems use a variety of technologies to determine if an obstacle such as a highway vehicle is blocking a crossing and provide an alarm to the train crew in sufficient time to stop the train before the crossing. These technologies are usually employed as backup to a barrier system such as four-quadrant gates, resulting in a highly secure system for the crossing. If the highway vehicle violates the gates, the train, under most circumstances, can still stop in time to prevent a collision. Intrusion detection systems employ various detection technologies such as inductive loops, microwaves, radar, video systems, and fiber optic strain sensors imbedded in rail structures to detect the presence of a vehicle or other obstacles. Several of these technologies are employed in Europe and Japan on high-speed rail lines. Research is currently being performed to assess the effectiveness of these alternative technologies. Results of this study will suggest which obstruction detection technologies are most suitable for use in high-speed rail corridors and should be evaluated further in field tests. A final report documenting the study will be released in late 1998. Upon approval of the FRA, demonstrations and evaluations of the recommended technologies will be conducted.

**Grade Crossing Hazard Elimination Projects** - Under the auspices of the Intermodal Surface Transportation Efficiency Act (ISTEA), Section 1010, funding is made available to the states for elimination of hazards at high-speed rail crossings. One of the grants was made to the State of Illinois to demonstrate a new barrier system technology at three grade crossings along the Chicago to St. Louis HSR corridor. The technology being evaluated is a Vehicle Arresting Barrier System (VAB). The VAB employs a net similar to that used on aircraft carriers to stop aircraft. The barrier has been crash tested at the Texas Transportation Institute facility where it successfully stopped a fully loaded (80,000 lb.) semitrailer in 100.5 feet.



Illinois Department of Transportation Section 1010 Demonstration Test

Installation of the VAB is scheduled to start in the spring of 1998, and the demonstration will last one year. Video cameras and electronic impact detection equipment will record any impacts and notify the local police and the barrier maintenance company. Evaluation of the VAB including human factors aspects will be performed by the University of Illinois.

**High-Speed Rail Grade Crossing Safety Demonstration Projects** - Section 1036 of ISTEA, provides funding to demonstrate new concepts for improving safety at High-Speed Rail (HSR) grade crossings. In support of these demonstrations, the FRA is developing an evaluation plan, providing technical assistance to local agencies, monitoring tests, analyzing data from the demonstrations, and providing independent assessment of findings. Three grade crossing demonstration projects were selected in response to the submission of 46 Expressions of Interest following a solicitation in the *Federal Register*. The first project, a crash-worthy barrier to prevent vehicles from entering the grade crossing produced a prototype system, but tests of the system revealed that it was too complex and costly to justify further development. The second project, a low-cost grade separation concept, was terminated due to site specific cost overruns.



Connecticut Department of Transportation Section 1036(c) Demonstration Test

The third project included a four-quadrant gate with obstruction detection and notification to the locomotive engineer to stop the train if an obstruction is detected. This project will be conducted at a crossing in Groton, Connecticut. Design of the train communications and control system is currently being performed. As part of the evaluation effort, video cameras have been installed at the crossing to observe driver behavior and system functioning both before and after installation of the new system.

**Broad Agency Announcement (BAA) - Grade Crossing Safety** - The FRA is soliciting ideas for improving HSR grade crossing safety through a BAA. A grant was recently awarded to the New York Department of Transportation under the Next Generation High-Speed Rail BAA to design, fabricate, test, and evaluate a low-cost, private grade crossing gate system suitable for low traffic crossings on high-speed corridors.

**Risk Analysis of High-Speed Rail Crossing Improvements** - The FRA currently has policy guidelines that recommend certain grade crossing warning and protection systems for various levels

of HSR passenger service. The FRA initiated an effort in 1995 to conduct a risk-based assessment of alternative grade crossing warning and protection systems to provide a quantitative basis for specifying enhanced guidelines. The assessment considers the risk reduction benefits and costs associated with alternative warning and protection device options as a function of train speed, train type, collision type, highway traffic volume and type of existing warning device. This information has been integrated in an analytical model to determine the most cost-effective warning and train protection solutions that meet safety objectives. The model has been applied to the Empire Corridor in New York as a case study. Additional risk assessment studies will be performed as new requirements and systems are defined. Recommendations for modifying the FRA guidelines will be made as appropriate.

**North Carolina Sealed Corridor Initiative** - The Sealed Corridor Initiative is a project to address every crossing in the 92-mile Charlotte to Greensboro segment of North Carolina's proposed high-speed rail corridor. The FRA has awarded a grant for the installation of innovative highway-rail crossing devices including (as median barriers) articulated gates, long gate arms, four-quadrant gates at crossings, and closing redundant crossings. Other elements of the initiative include traffic separation studies to consolidate crossings, video enforcement, video monitoring and data collection, studies of driver behavior and the demographics of violators, innovative warning devices, and use of improved signs at private crossings. The FRA will evaluate this project and work with North Carolina Department of Transportation to develop guidelines for enhancing safety on other high-speed rail corridors.

## INTELLIGENT TRANSPORTATION SYSTEM CONCEPTS

---

The Intelligent Transportation Systems (ITS) program was established at the U.S. Department of Transportation in 1991 in response to the Intermodal Surface Transportation Efficiency Act (ISTEA). Managed by a Joint Program Office consisting of staff from the Federal Highway Administration, Federal Transit Administration, and National Highway Traffic Safety Administration, the ITS program is aimed at bringing new communication and information technology to bear to make the U.S. transportation system safer and more efficient.

The following projects describe the application of ITS technologies to highway-railroad grade crossings.

**Vehicle Proximity Alert Systems** - Vehicle Proximity Alert Systems (VPAS) are designed to give priority vehicle operators (emergency, police, fire, school bus, hazmat, etc.) advance, in-vehicle warnings of the approach or presence of a train at a grade crossing. This warning would give operators time to stop safely. Section 1072 of ISTEA directs the FHWA to coordinate field testing of VPAS, and to determine their effectiveness as safety devices.

In 1993, a joint committee of FHWA and FRA members selected three systems for testing. Each system represented a different technological approach for alerting vehicles. The AAR/TTCI tested the three prototype systems, the results of which are currently being evaluated by the Volpe Center.

Of the three systems tested, the two that operated by radio frequency transmission appeared to be the least susceptible to environmental impacts, but tended to give excessive warning time with slow-moving trains. The third system, used the acoustical signature of the train's horn as its mode of detection. Additional testing of VPAS systems will be performed under more realistic field conditions. Results of these tests will provide a basis for developing standardized specifications and test procedures for Vehicle Proximity Alert Systems.

**Advanced Train and Vehicle Detection Technologies** - This project is supported by a grant from the FRA to Union Switch and Signal with matching funding from the grantee. This system employs fiber optic sensors in the rail tie plates and embedded into the roadway, advanced digital signal processing, and neural networks to detect trains and vehicles at grade crossings. The use of digital signal processing and neural networks will allow the system to recognize motoring traffic pattern signatures to determine anomalies at the crossing, such as stalled roadway vehicles, to prevent collisions with approaching trains. Other uses of this technology, although not part of the project, involve rail structure hazard detection on railroad bridges and curves using the fiber optic sensor/neural network system to make precise, real-time measurements of rail alignment.



VPAS Data Collection

**Intermodal Dynamic Traffic Control System** - In coordination with the FHWA's ITS Joint Program Office, the FRA will develop an intermodal dynamic traffic control system using real-time continuously updated train location data available from the implementation of advanced communications-based train control systems. The system will interconnect the crossing warning systems with highway signal systems, positive train control

systems, and advanced traffic management systems. The system will focus on corridor segments of special traffic flow (school buses, and hazmat vehicles) and provide advanced information to warn drivers approaching a grade crossing of a train's approach to or blockage of a crossing. The highway traffic management system can then reroute the traffic around the occupied crossings to minimize delays to motor vehicles.

**Intelligent Grade Crossings** - Grade crossing safety is being enhanced as part of efforts to develop improved train control systems. The railroad industry and suppliers are examining alternatives to track-circuit-based signal activation. Some systems include Global Positioning Satellite systems to achieve automatic vehicle location, speed, and direction. These projects will investigate and evaluate communications based train control systems as part of demonstration projects in Michigan and Washington states. These projects will include the development of smart or intelligent grade crossing controllers. In Michigan, improved crossing operations are a key aspect of the incremental train control system being demonstrated. The locomotive uses a digital radio to contact the crossing warning system, providing a longer warning time and confirming that the crossing warning system is operating properly, enabling train operations at higher speeds without having to modify the

extensive track circuitry. In Washington, the positive train separation system will also be linked to grade crossings.

**Long Island Rail Road Project** - Another concept for an intelligent grade crossing is being developed by the Long Island Rail Road with FHWA funds and with active FRA participation. This system is being developed by the General Railway Signal Company and will tie the local grade crossing gate controller to both the train control and the highway traffic signal systems to minimize motorist delays in the vicinity of urban stations. Demonstration of the system is scheduled to begin in late 1998.

**Innovations Deserving Exploratory Analysis (IDEA) Program Projects** - The IDEA Program, sponsored by the Transportation Research Board (TRB), has resulted in several awards for research projects that have potential significance for highway-railroad grade crossing safety. Recent awards were to investigate technologies that could be used to provide better warning to a motor vehicle driver of the approach of a train and to detect the presence of a train approaching a grade crossing. The FRA will assess the IDEA projects related to crossing safety. Activities may include coordination and definition of work, technical direction, review of results, and independent assessment of findings.



# HAZARDOUS MATERIAL





# HAZMAT TRANSPORTATION SAFETY

---

Of the 210,000 tank cars in the North American freight car fleet, nearly one-half carry materials that are flammable, corrosive, poisonous, or pose other hazards. About 1 million shipments of hazardous materials (hazmat) are made via tank cars each year.

Tank car safety research is conducted by the FRA, partially in a cooperative effort with the Association of American Railroads/Railway Progress Institute (AAR/RPI) Tank Car Committee. FRA-sponsored research focuses on problems related to fatigue, fracture, and welding in the current tank car fleet, as well as on improving standards and procedures for future tank car design.

## Reliability of Tank Car Fleet

The reliability of a tank car may be defined as the probability that, when operating under stated environmental conditions, the tank car will perform its intended function adequately for a specified interval of time. Although complete and catastrophic failure is easily recognized, the integrity of the tank car for the purpose of safe packaging for hazardous materials can deteriorate gradually over time. To avoid catastrophic failures, it is essential that potentially unsafe conditions are recognized and remedied before a failure results. To achieve this objective, the behavior of safety critical components, under both normal and extreme conditions, must be considered.

Knowing the reliability of each tank car is the key to preventing catastrophic failures. However, reliability is a function of many design and operating variables. A methodology to account for the effect of these variables on reliability is being developed. Accurate reliability assessments will provide tank car owners with the quantitative information needed to determine safe and cost-effective inspection and maintenance procedures, which help to ensure the safe transport of hazardous materials.

The work being conducted to develop the methodology for determining and improving tank car

reliability includes characterizing the service environment for tank cars, determining the behavior of tank cars under normal service conditions, and extreme conditions, such as derailments. Specific programs to investigate these issues are described in the following sections.

## Characterization of Lading and In-Service Environment Loadings

**Tank Car and Tank Car Lading Compatibility** - The objective of the tank car and tank car lading compatibility project is to develop a process to ensure that lading is carried in tank cars that are compatible with safety requirements of the lading. For example, the thermodynamic properties of some materials, such as methacrylate monomers, can cause excessive pressures when the tank car is exposed to fire. It is important that tank cars carrying such materials have pressure and vent capacity to accommodate this high-temperature behavior. The tank car and tank car lading compatibility project examined a wide range of lading materials for specific safety requirements and has developed new guidelines for lading-specific tank car requirements.

**Designing Normal Service and Extreme Service Forces Into Tank Car Structural Integrity** - A few incidents of tank car structural damage and failure have occurred without prior warning to train operators; i.e., under completely “normal” operating conditions. As a result, the tank car industry is currently studying the use of damage tolerance analysis (DTA) to provide continued tank car integrity. The aim of damage tolerance methodology is to accurately predict the growth of potential flaws in a structural system, so that parts are inspected and, if necessary, repaired or replaced before any flaws become critical. To incorporate this approach into the tank car industry, an improved understanding of the in-service loads (load spectrum) experienced by tank cars is needed.

The goals of this research project are 1) determine the loads experienced by tank cars under normal service conditions, 2) determine the loads experienced by tank cars under severe loading conditions (e.g. coupling at excessive speeds), and 3) use these loads to design mechanical tests to simulate actual tank car service under controlled, laboratory conditions.

Currently, there exists a load spectrum, given in Chapter 7 of the Association of American Railroads Manual of Standards and Recommended Practice, known as the Freight Equipment and Environmental Sample Test (FEEST), which is used to represent service conditions for freight cars in laboratory and numerical simulations. However, there are some questions regarding how well FEEST represents the loads encountered by tank cars. Data from completed research has been used to develop a load spectrum that is more representative of loads experienced by tank cars. The new spectrum has been used to design mechanical tests that represent the service environment of tank cars.

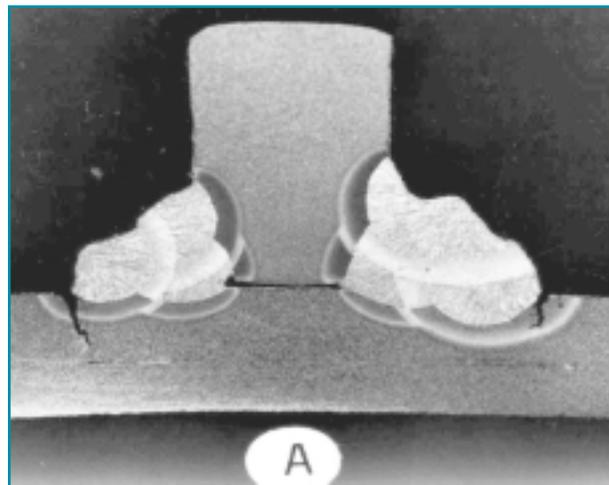
Similar research is needed for forces and impacts experienced in accident scenarios. These data have not been compiled for ready reference, and might not exist at all. These data are required to validate critical flaw size calculations. Data will be gathered from literature, industry data bases, and from application of engineering principles. It is anticipated that this dataset will evolve over time.

## Behavior Under Normal Conditions

**Determination of Critical Flaw Size in Tank Cars** - The development of viable guidelines for critical flaw sizes in tank car components is critical to the application of damage tolerance analysis for the safe operation of tank cars. Every component of a tank car has a critical flaw size - the crack size for which failure is likely under operational loads. Critical flaw sizes must be known for all fatigue sensitive locations to define non-destructive testing performance criteria and intervals. To determine critical flaw sizes, both the stress state and material behavior of a tank car components must be well understood.

Recent work in the areas of structural integrity - including fracture-mechanics-based DTA of tank car stub sills - exposes a need for a compilation of past testing to catalog the range of known material properties, and to define additional work necessary to document fracture toughness (the ability of a material to resist cracking). In recent years, investigations have shown that fracture toughness is a strong function of specimen geometry. This dependence makes it difficult to predict large-scale structural behavior based on the results from small scale laboratory tests results. Further research is required to incorporate state-of-the-art theories on fracture initiation and propagation into finite element models for tank car damage evaluation.

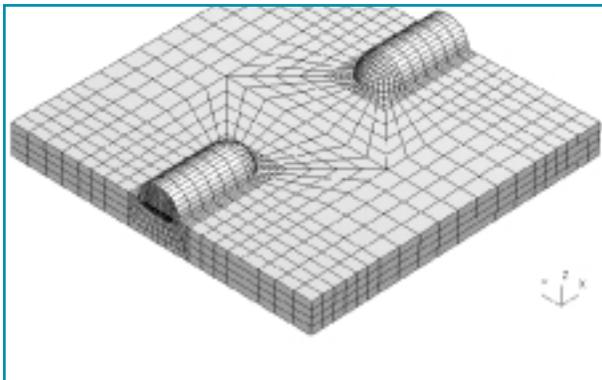
**Residual Stresses and Welding Practices** - Premature failure of tank car shells in tank cars containing hazardous materials poses a significant threat to public safety and the environment. A significant number of cracks that occur in the shells of railroad tank cars are near welds. A cross section of a welded skin/stiffener detail is shown below. Small cracks can be seen near the boundaries of the welds. The development and growth of these cracks are affected by residual stresses that are induced by the welding process. Understanding these changes will help to develop recommendations for improved welding practices, inspection strategies, and inspection frequencies to avoid catastrophic failure or leaks in tank cars.



A research project is underway to develop the capability to numerically predict residual stresses asso-

ciated with welding procedures. Results from preliminary analyses indicated that significant tensile residual stresses, which would encourage the formation and growth of fatigue cracking, could be expected in the tank car shell near the ends of skip welds.

Laboratory specimens with skip welds were fabricated by the Oregon Graduate Institute (OGI). The configuration of these specimens consists of a pair of skip welds that have been laid on a plate of conventional shell material. These laboratory specimens were used to determine residual stresses resulting from the welding process, using a destructive technique known as blind hole drilling. Further confirmation of the residual stress state resulting from welds was obtained by blind hole drilling measurements at the ends of skip welds in actual tank car shells. However, the techniques used for these tests are not capable of determining the through-the-thickness residual stress gradients caused by the welding process. In 1994, the National Institute of Standards and Technology (NIST), under a reimbursable agreement with the DOT, conducted additional measurements using the laboratory specimens remaining from the OGI project. In this case, the through-the-thickness distribution of residual stress was estimated non-destructively by means of a combination of x-ray and neutron diffraction measurements.



In 1995, in support of the FRA, the Volpe Center began to develop the methodology to perform 3-dimensional, thermo-mechanical, elastic-plastic finite element analyses to predict the through-the-thickness distribution of residual stresses produced by welding. Accurate geometric models of the specimens tested by NIST were used, so that the numer-

ical results could be validated by comparison to experimental results. A typical mesh is shown in the accompanying figure.

The procedure to numerically predict the residual stresses in the tank shell involves simulation of the cooling of the hot weld bead on the cooler base plate. During this process, the bead shrinks on the stiffer plate. The resistance of the plate to shrinking causes stresses to develop. Preliminary results from the finite element modeling were published as part of the proceedings from the 1997 IEEE/ASME Joint Railroad Conference. The general agreement between the numerical simulation and the experimental measurements illustrates the viability of the analysis methodology. Future work will involve using the validated methodology to investigate the sensitivity of residual stresses to parameters that can be controlled by design or shop practice, thereby improving future welding practice.

## Behavior Under Extreme Conditions

**Puncture Resistance of Tank Cars** - Scale model and full scale puncture velocity tests conducted in the 1970s and early 1980s led to regulations for head shields for tank cars carrying certain hazardous materials. Further tests on tank cars made of aluminum and tank cars designed for transporting chlorine were performed in the mid-1980s. Research sponsored by the AAR/RPI developed a set of semi-empirical equations to predict the velocity at which tank car shells, both with and without head protection, would puncture.

In previous research sponsored by the AAR/RPI, a set of semi-empirical equations was developed to determine the velocity at which puncture of the shell, with and without head protection, would occur. In research sponsored by the FRA in 1996, the general applicability of these equations was examined by comparing results from the equations to puncture data available in the open literature. A recent FRA research project used the existing set of experimental data to evaluate the semi-empirical equations for puncture velocity. Predictions from the semi-empirical equations for puncture velocity are within reasonable agreement with experimental data. The agreement between predictions and experimental data becomes worse, however, when

shield protection is present and when the tank is internally pressurized. In cases involving shield protection, the calculated puncture velocity tends to be conservative (lower than the observed test cases). More detailed computational models, based on finite element analysis, are being developed to predict the puncture velocity of tank car shells. These models will enable more efficient design of shield protection, and to predict the effects of pressurization on tank car behavior in accident scenarios.

**Tank Car Damage Assessment** - Emergency responders must make on-the-spot decisions regarding the best course of action to follow in the aftermath of an accident. These decisions must be made in a timely manner and, therefore, are often without the benefit of either complete information or a detailed analysis. A tank car accident in Waverly, Tennessee in the 1970s resulted in the death of a number of emergency responders when a tank car ruptured unexpectedly. The tank car had an undetected crack that grew over several days and caused the disaster. The AAR's Bureau of Explosives has developed a set of guidelines to protect emergency personnel when responding to hazardous materials accidents. These guidelines are derived from the opinions of technical experts, and based on visual inspection of the accident scene. The current emergency response guidelines are being reviewed for adequacy, timeliness, and accuracy, to ensure that emergency responders can make field decisions based on the best technology and information available. These guidelines will be updated periodically when new technologies emerge.

## Development of Next Generation Tank Car Fleet

Improvements in materials, materials processing, and damage tolerant design methodology will lead to improved cost effectiveness and reliability for the next generation of tank car designs. The FRA is sponsoring and performing research to improve the understanding of the effects of manufacture, processing, geometry, and service loads on the behavior of materials in use in tank cars. New materials and materials processing are discussed in the following sections.

**Tank Car Steels** - Materials under consideration for tank car construction require certain minimum mechanical properties. This project will develop an efficient procedure whereby potential materials for tank car construction can be identified based upon mechanical behavior. A report will be prepared to include all prior and current work in this area.

**Improved Manufacturing Practices** - Shell materials with improved fatigue and fracture resistance properties can be utilized to improve the next-generation hazmat tank car fleet. In 1994, the FRA began studies to explore the possibilities of producing economical, fracture-resistant plate stock for tank car shells. The microstructure of standard carbon steel is pearlite. Uniform microstructure consisting of carbide-free bainite could lead to improved performance of tank car shells.

The automotive industry currently uses a process known as thermo-mechanically controlled processing (TMCP) to produce sheet products (0.1-inch thick or less) with a bainitic microstructure. However, tank cars are manufactured from steel plates which are considerably thicker than the sheet products that currently undergo TMCP. In 1995, a transient heat transfer model was developed to examine the range of possible TMCP processes for production of the desired bainitic microstructure in plate thicknesses appropriate for tank car construction. Results from the model suggest that the desired microstructure can be achieved through accelerated cooling of the material. Furthermore, a metallurgical study completed in 1996 indicates that the desired microstructure also can be achieved through the proper selection of alloy additives. These studies indicate that plate thicknesses of carbon steel with improved fracture and fatigue resistance can be manufactured. However, the economical manufacture of large quantities of such material has yet to be addressed, and is a topic for future research.

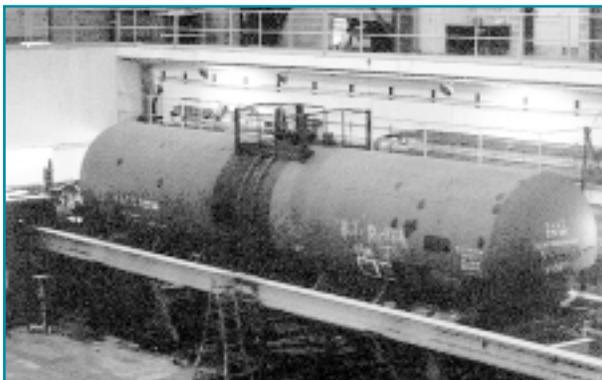
## Damage Tolerant Design Methodology

**Development of Damage Tolerant Tank Cars** - Following investigations of two 1992 railroad accidents where hazardous materials were released from tank cars due to structural failures at pre-existing cracks, the National Transportation Safety

Board (NTSB) issued a special investigative report with recommendations to the FRA and industry. One of these recommendations was the development of a damage tolerance approach to the inspection and design requirements of tank cars. The damage tolerance approach was originally adopted by the U.S. Air Force for military aircraft and is now embraced by the airline industry for commercial transport airplane design. The basic concept behind damage tolerance is to ensure a high probability (through inspection and fracture-mechanics-based crack growth analyses) that critical components are inspected at some time between when a crack is first detectable and when it becomes large enough to cause failure of the component under expected service conditions. The damage tolerant analysis methodology might indicate some components where the design that promotes rapid flaw growth. In these cases, redesign or retrofiting might be attractive alternatives to short inspection intervals.

To facilitate the incorporation of damage tolerant design into the rail car industry, the FRA sponsored research to conduct stress analyses on two stub sill tank car designs, with and without head braces. Upon completion of these analyses, the major tank car builders initiated projects to develop finite element models for their own designs. Flaw growth rate predictions using the results of these stress analyses, were initiated. The results of these analyses will suggest both inspection intervals and design modifications for retrofit and/or future tank car designs. Similar analyses are planned for other critical areas of tank cars.

In 1994, the FRA, AAR, and RPI, initiated a joint program to complement the numerical analyses. To investigate the load environment experienced by a stub sill tank car in revenue service, full-scale tests



were performed at TTC to estimate the in-service load environment. A car, provided by Union Tank Car Company, was instrumented by AAR/TTCI to measure coupler loads, car body strains, truck loads, and tank surge pressure. The accompanying photograph shows this tank car mounted in the simuloder facility at TTC. It was then equipped with a self-contained data collection system and a Global Positioning System and placed in service as an over-the-road test. Between August 1994 and March 1995, the tank car accumulated approximately 15,000 miles of in-service use.

The data accumulated in the over-the-road test were analyzed in several ways. Strain gage and coupler load data were analyzed using rainflow techniques which allows the user to accumulate the number of load cycles (peak-valley) experienced over a pre-set range. This methodology allows for great data compression, and provides results directly compatible with fatigue life models. It was found that significant fatigue damage was caused by large loads in the couplers in both the longitudinal and vertical directions.

Southwest Research Institute has been acting as an independent third-party program manager to provide oversight and guidance to this program while maintaining a confidential relationship with respect to the proprietary information of the tank car manufacturers. A report on their work is expected at the end of FY 1998. Future research needs in this area will be addressed upon review of this report.

**Improved Inspection Systems** - Under FRA regulations, tank car owners are required to employ periodic structural integrity inspections, including tank shell thickness tests and inspections of tank car welds. Detection of defects and other types of damage through non-destructive evaluations (NDE) can be difficult, especially when the tank cars are covered with a layer of insulation or lining material. By concentrating the required inspection to known areas of crack initiation, DOT's Research and Special Programs Administration and the FRA expect improvement in the reliability and efficiency of the inspection, and thereby a reduction in the inspection costs.

DOT authorizes five NDE methods which include dye penetrant, radiography, magnetic particle, ultra-

sonic, and optically-aided visual inspection. Other NDE methods may be used by DOT exemption. Rule HM175A/201 requires tank car repair facilities to document the sensitivity and reliability of the NDE methods used for the structural integrity inspections.

In light of the large number of welds on tank cars that need to be inspected to meet the structural integrity requirements of HM175A/201, the development of global NDE will significantly improve the probability of finding defects. Currently, acoustic emission evaluation of tank cars is providing not only information about the welds that must be inspected under the new requirements, but also about any defects on any part of the tank shell. Further evaluations of acoustic emission technologies as well as the development of other highly sensitive global NDE methods will increase the probability of finding defects.

A recommendation of the special investigative report written by the NTSB was to evaluate NDE methods which could be used in prescribed periodic inspection of all tank cars transporting hazardous materials. Acoustic emission was evaluated in 1996 as an NDE method to detect damage in welds and in the parent metal. Neutron radiography was examined as a method to determine subsurface weld strength. Another NDE activity will involve the development of a defect specimen library which would be useful for training and qualifying NDE technicians. In 1996, the AAR/TTCI began an investigation into the currently used methods of tank car inspection, with the ultimate goal of replacing or enhancing the prescribed hydrostatic testing of tank cars. The AAR/TTCI, in coordination with the AAR Tank Car Committee and with the RPI, selected four cars for testing. Baseline acoustic emission testing began in 1997.

NDE testing is currently underway. The railroad industry has provided tank cars that will serve as test subjects for the tests, as well as field support for the development of baseline inspection processes. A final report on this research is expected by the end of 1998. Once the baseline testing has been completed, at least five other non-destructive testing

techniques will be used to evaluate the selected tank cars. The results of these tests will be compared with the baseline data to evaluate the effectiveness of the various NDE methods.

**Shelf Coupler Height Mismatch Effects** - Double-shelf couplers are designed to prevent uncoupling in an accident or incident involving severe braking. To prevent the release of hazardous materials due to the puncture of a tank head by an uncoupled coupler, double-shelf couplers are prescribed on all tank cars in hazardous materials service. However, it is suspected that the stiff double-shelf coupler design increases stresses in the stub sills, and has caused premature fatigue failure in certain tank cars. This project will examine the coupler-to-coupler interface and the draft-coupler assembly interface as a dynamic system to determine the forces resulting from the use of a double-shelf coupler. The study will recommend appropriate changes to the shelf coupler design to prevent further premature fatigue failures.

**Heavy Gross Weight Tank Cars** - Tank car builders and owners are currently submitting applications to the DOT for the use of rail cars with gross rail loads exceeding 286,000 lbs. Fatigue analyses on these designs are performed using FEEST-type loading spectra. However, the longitudinal and vertical coupler loads in these spectra should be scaled or modified to account for the increased gross weight of the cars. Currently, no regulatory requirements exist for the design of heavy gross weight cars. Before such a requirement may be considered or put into place, a study of appropriate scaling factors must be made.

The effect of increased gross weight on rail car loads and behavior are being determined through a review of past FRA research utilizing the Train Operation and Energy Simulator and by developing ADAMS computer models. Heavy gross weight tank cars might be more prone to buckling than current cars are. This issue will be investigated through finite element modeling. These studies will result in guidelines for tank car manufacturers to use when designing heavy gross weight rail cars.

## TANK CARS - FIELD PRODUCT REMOVAL

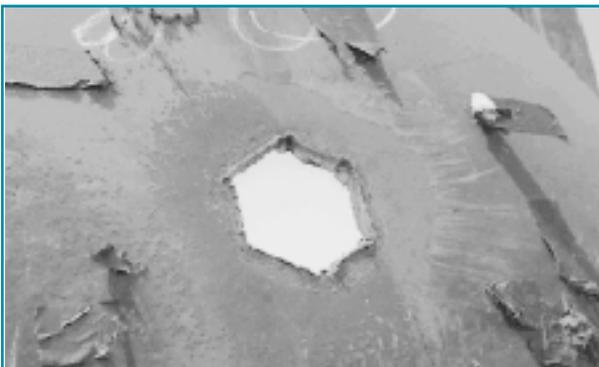


Placing Charge on Jacket

During derailment accidents, tank cars may become structurally compromised by dents, cracks, or punctures, and/or be subject to external heating. This compromise in structure, combined with increased internal pressure, can lead to catastrophic failure. The FRA tasked the AAR/TTCI's Hazardous Materials Training Center to research and develop safe, reliable operating procedures for field product removal.

### RESEARCH STATUS

In this investigation, explosive charges were used to cut holes in tank cars to release internal pressure and to initiate a controlled release of product. Testing was performed on a sample tank car head and on four full-scale DOT112T340W tank cars.



Jacket Cut by Explosives

Various combinations of jacketing, insulation, and thermal protection materials were explosively cut.

Mathematical modeling was used to determine the optimum vent and drain hole sizes, and to predict both vapor and liquid evacuation rates. Testing validated the mathematical models within acceptable limits.

### KEY FINDINGS

As a result of this research program, *The Handbook for Vent and Burn Method of Field Product Removal* was developed. This handbook provides hazardous materials response professionals with a field guide of vent and burn procedures.

### FUTURE RESEARCH

None. The vent and burn project is complete, having resulted in the publication of the referenced Handbook.



Foam Backed Charge on Tank



Water Draining from Tank



# TRAIN OCCUPANT SAFETY





## EMERGENCY PREPAREDNESS

### SUMMARY

The Federal Railroad Administration, in partnership with Amtrak and commuter passenger train systems, is stressing the need for advance planning in order to respond effectively to emergencies. This planning addresses emergency response procedures, training of system operating and other emergency response organization personnel, and the provision and use of emergency equipment.

### RESEARCH STATUS

The Volpe Center reviewed the emergency preparedness practices in use by Amtrak and the various commuter rail operations nationwide as well as relevant information on policies and procedures from the transit industry. This information, as well as additional emergency preparedness procedures developed by Volpe Center staff, served as the basis for the report, *Recommended Emergency Preparedness Guidelines for Passenger Trains*, published by the FRA in 1993. The guidelines are intended to assist passenger train system operators to assess, develop, document, maintain, and improve their emergency response capabilities, and to coordinate these efforts with emergency response organizations in a manner which best protects the traveling public and system passenger trains and facilities. The recommendations provide a useful framework for these organizations to evaluate and, if necessary, modify or supplement their emergency preparedness plans and procedures, and related training, and passenger train and facility equipment design and operations.

The development of the recommended guidelines document was supported by representatives from Amtrak and several commuter rail systems. These representatives provided important inputs regarding their emergency response programs, and the practicality of the recommendations. Rail system management and labor representatives also provided



Emergency Exit Window

input into the Passenger Train Emergency Preparedness Final Rule.

The recommended guidelines report serves as a baseline resource document in the development of the FRA's passenger train emergency preparedness component of the Passenger Equipment Safety Standards, which the FRA was required to develop as a result of the 1994 Swift Rail Act.

### FUTURE RESEARCH

Now that a framework for emergency planning has been created, the FRA Office of Research and Development has requested that the Volpe Center conduct a study that concentrates on specific, safety-sensitive details related to emergency evacuation. These topics include: emergency exit size, type and location; emergency lighting levels; signage, and exterior rescue access.

The passenger train evacuation study is being coordinated with work performed by the American Public Transit Association (APTA)/Passenger Rail Equipment Safety Standards (PRESS) Committee.

The FRA Office of Research and Development staff continues to work with the various operating entities responsible for passenger rail services through industry workshops, emergency drills, and training needs development.

## FIRE SAFETY

In 1989, the Federal Railroad Administration reissued fire safety guidelines (first published in 1984) which address the flammability and smoke characteristics of materials used in intercity and commuter passenger cars. The European fire safety approach uses test methods similar to the FRA guidelines, but certain differences of potential concern have been identified as a result of preliminary safety reviews of the German maglev and French TGV technologies by the FRA.

In 1993, the National Institute of Standards and Technology (NIST) completed a comprehensive evaluation of the U.S. and European approaches to passenger train fire safety for the FRA. In addition to test methods for material, the effects of vehicle design, detection and suppression systems, and emergency egress were reviewed. A major conclusion of the NIST study was that the use of fire hazard and fire risk assessment supported by measurement methods based on heat release rate (HRR) could provide a means to better predict real world fire behavior.

### RESEARCH STATUS

A demonstration program is now underway to validate the use of HRR test methods as an alternative to the currently cited FRA test method. This program consists of the following phases:

Phase I: Evaluate selected materials that have been tested according to older test methods, using HRR test method technology. The evaluation included the comparison of Cone Calorimeter HRR test data and

test data from current FRA cited tests methods and performance criteria. Necessary quantitative data was used as an input for a fire hazard analysis, using a computer model specific to passenger train vehicles. Phase I work has been completed and a report published, entitled *Fire Safety of Passenger Trains - Phase: Material Evaluation* in the Cone Calorimeter, Interim Report, DOT-VNTSC-FRA-98-2.

Phase II: Evaluate the applicability of a hazard analysis using a computer fire model of the overall fire safety of passenger trains. The evaluation included conducting furniture calorimeter tests to provide additional HRR data. Material controls and vehicle design, detection and suppression systems, and emergency egress and their interaction were analyzed to assess the relative impact on fire safety for a range of design parameters. The Phase II tasks have been completed and a report is in final preparation.

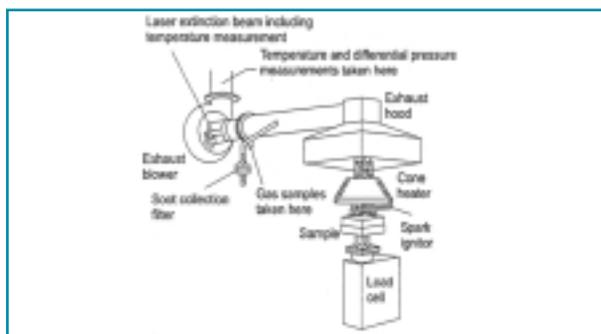
Phase III: Perform selected real-scale proof testing of a complete full-size rail car to verify the small-scale HRR criteria and hazard analysis studies in actual end use configuration.

### KEY FINDINGS

The results of the Phase I study demonstrated strong correlation between the flammability smoke emission data generated from the existing FRA fire safety guideline-cited test and heat release rate data generated from the Cone Calorimeter.

### FUTURE RESEARCH

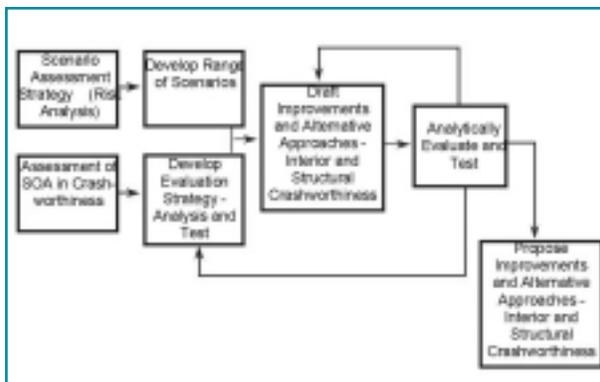
Finally, since fire safety has been identified as an important element of overall system safety for the new passenger train technologies, work will continue to provide additional general fire safety support to the Office of Safety. The support will include technical consultation with Amtrak regarding the fire performance of material proposed for new high-speed train sets, as well as new conventional train equipment. Worldwide developments concerning methods for preparing for and dealing with fires in railroad tunnels also will be monitored.



Cone Calorimeter Test Apparatus

# COLLISION MECHANICS, CRASHWORTHINESS, AND OCCUPANT PROTECTION

In order to provide a framework for this effort, collision safety research has been grouped into two categories: **collision scenario assessment, and interior crashworthiness**. Collision scenario assessment is the analytic evaluation of the intended application of passenger equipment in order to identify the potential collisions in which the equipment may become involved and the evaluation of accident data to determine the causes of injury and fatality. Interior crashworthiness is comprised of those features of the train crew and passenger volumes which act to limit the forces and decelerations imparted to the occupants to survivable levels during a collision.



Collision Safety Research Project

## Collision Scenario Assessment

Vehicle crashworthiness requirements are defined by the collision scenarios in which the vehicle is likely to become involved. In turn, the likelihood of these scenarios is dependent upon the system in which the train is operated and the features of the system and measures taken to avoid these scenarios.

The primary objectives for structural crashworthiness are to maintain the integrity of the occupant compartment and to control the deceleration of the occupant compartment. The occupant compartment must be able to preserve at least a minimum occupant survival volume, be able to minimize local

compartment penetration, and be able to ensure occupant containment within the compartment space. In order to minimize injury, the accelerations and forces imparted to the occupants must be kept sufficiently low during a collision. In order to meet this objective, the occupant compartment must be decelerated at a sufficiently low rate. In order for this deceleration to be sufficiently low, the vehicle structure must be able to absorb an appropriate amount of energy.

## Interior Crashworthiness

In order to minimize injury, the accelerations and forces imparted to the occupants must be kept sufficiently low during a collision. These decelerations and forces depend upon the interior arrangement as well as the deceleration of the occupant volume (crash pulses). To minimize the effects of secondary impacts, the interior of the compartment must be appropriately contoured and padded. To eliminate as many secondary impacts as possible, luggage and interior fixtures must all be adequately restrained. How well a particular interior arrangement minimizes injury can be evaluated for a range of potential occupant volume crash pulses.

## RESEARCH STATUS

Recent crashworthiness research includes the following:

- Assessment of the State-of-the-Art
- Accident Avoidance
- Accident Survivability
- Analysis of High-Speed Crashworthiness Options
- Locomotive Crashworthiness Research
- Rail Vehicle Crashworthiness Symposium
- Dynamic Sled Testing of Passenger Seats

A description of each of these research areas follows.

**Assessment of the State-of-the-Art** - The Volpe Center has been supporting the FRA by creating and analyzing various collision scenarios and developing safety guidelines and specifications for high-speed ground transportation (HSGT). Existing U.S. and foreign rules and regulations, standards, and practices were reviewed as a starting point for this project. The FRA has put forth a comprehensive effort to develop the technical information necessary for regulating the safety of HSGT.

In recent years the interest in HSGT has increased. All the systems proposed for operations at speeds greater than current practice employ technologies that are different from those presently in use. The greater potential consequences of an accident at high speeds require the assurance that HSGT systems are safe for use by the traveling public and operating personnel.

**Accident Avoidance** - Collision safety comprises the measures taken to avoid collisions and ensure passenger and crew protection in the event of an accident. The results of studies conducted provide a basis for evaluating the collision safety provided by a given HSGT system.

Collision avoidance is accomplished in three ways. The first method is to determine the integrity of the route. The idea is to ensure that the track or guideway is clear of other trains, vehicles or obstructions. Modern software driven in microprocessors are used to control this interlocking system. The second part of collision avoidance relates to the communication of the authorized movements to an operator or to the control system which can be an automatic train operating system. The final control element is speed. This function is carried out by the automatic train protection (ATP) system. The control of the speed and the enforcement, that is, the ability of the system to override the operator, are included in the functions supplied by the safe-speed enforcement part of the control system. Continuous ATP systems maintain a constant guideway-to-train communication. Coded track circuit systems of this type are in use today in other countries.

**Accident Survivability** - This involves a number of issues including the structure of the vehicle - its design parameters, the interior fittings, and window

glazing. The structure should be designed to optimize the absorption of collision forces in areas that are not occupied by passengers. The occupants need to be protected during the second collision; that is, the one where they are in motion and the vehicle is not.

**Analysis of High-Speed Crashworthiness Options** - The Volpe Center has been providing support to the FRA in developing the technical basis for crashworthiness specifications for rail passenger equipment. The work described here is a part of the High-Speed Ground Transportation Safety Program of the FRA. The results of these studies have been used in discussions with Amtrak on safety considerations related to the purchase of Northeast Corridor high-speed trainsets.

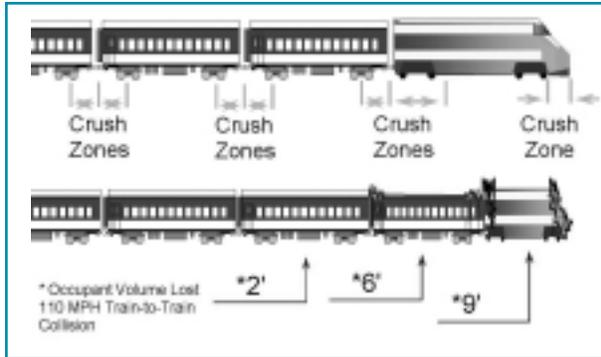
The FRA evaluated different strategies for the design of rail vehicle structure to protect the occupants. There are two types of collisions with which to deal. One is the primary collision between the train and the impacted object. The second is between the occupants and the interior including loose objects inside the train such as baggage.

Causes of fatalities include crushing of the occupant in the primary collision and excessive deceleration of the head or chest of the occupant and axial neck loads during the secondary collisions inside the train.

Conventional design practice results in cars of the uniform longitudinal strength. The crash energy management system requires varying strength through the train. High strength is required in the occupied areas and lower strength in the unoccupied areas.

The interior configurations were studied considering data on head injuries, chest deceleration times, and axial neck load. These issues are all part of the secondary impact problem.

The use of compartments can be as effective as a lap belt in minimizing the probability of a fatality. Compartmentalization is a method of occupant pro-



**Constrained Crash Energy Management Design**

tection that requires seats or restraining barriers to be positioned in a manner that provides a compact, cushioned protection zone surrounding each passenger.

Three different interior configurations were evaluated for effectiveness involving lap belts and lap belts with shoulder restraints. The interior configuration influences which interior surface the occupant strikes and which part of the occupant strikes the interior. Vehicle deceleration influences how hard the occupant strikes the interior surface.

Additional data on secondary impacts are needed. The most effective way to reduce injury in train collisions may be to gather information from the victims of actual accidents. Detailed structural analyses and testing are needed to develop structures which implement the crush zones and to evaluate the potential for increased occupant volume strength.

**KEY FINDING**

One principal conclusion is that a sufficiently compartmentalized interior protects the occupants against fatality during train collisions at least as well as required in the automotive and aircraft industries. Seat belts provide some level of increased protection from fatality owing to secondary collisions; however, most fatalities during train collisions are predicted to be from loss of occupant volume.

**Locomotive Crashworthiness Research** - In September 1992, Congress passed Public Law 102-365, the Railroad Safety Enforcement and Review Act (RSERA), requiring, in part, that the Secretary of Transportation conduct research and analysis to consider the costs and benefits of several types of crashworthiness improvement features. These features include braced collision posts, crash refuges, rollover protection devices, uniform sill heights, deflection plates, anticlimbers, shatterproof windows, and equipment to deter post-collision entry of flammable liquids.



**Locomotive-locomotive Collision, 30-mph Closing Speed**

As part of the response to RESRA, computer models were developed and related engineering calculations were made to analyze the crashworthiness of the cab area in existing road freight locomotives. In addition, the models provided quantitative estimates of the costs and benefits of the crashworthiness improvement features.

The study team performed its evaluation using the Association of American Railroads (AAR) industry standard, S-580. This standard applies to new road-type locomotives built after August 1, 1990, and requires three of the features listed above: collision posts, anticlimbers, and the short hood feature that

TOTAL OCCUPANT VOLUME LENGTH LOST (feet)		
COLLISION CLOSING SPEED (mph)	CONVENTIONAL DESIGN	CRASH ENERGY MANAGEMENT DESIGN
35	0	0
70	9	2
110	22	17
140	69	57

is considered, in part, as equipment to deter post-collision entry of flammable liquids.

**KEY FINDING**

The study found it feasible to provide practical improvement to freight locomotive crashworthiness by making modifications to some of the features listed in the Public Law. In particular, an increase in the strength of the collision posts over that specified in S-580 appeared to provide the clearest benefit. Implementation of a deliberate crash refuge and use of glazing with higher penetration resistance also appear to be feasible for practically improving crashworthiness. An interlocking anticlimber with closely matching underframe neutral axes (rather than sill heights) will provide increased protection against cab crush, especially when used with the stronger collision post concept.

**Rail Vehicle Crashworthiness Symposium** - The Rail Vehicle Crashworthiness Symposium, sponsored by the FRA, Office of Research and Development, was held at the Volpe Center on June 24-26, 1996, and was attended by 95 members of the international community of rail transportation experts. The objective of the symposium was to present results of current research on rail vehicle collision safety and passenger rail equipment crashworthiness design and to provide a forum for exchange of technical information between research organizations, passenger railroad operators, equipment manufacturers, and constituent organizations concerned with rail passenger car collision safety.

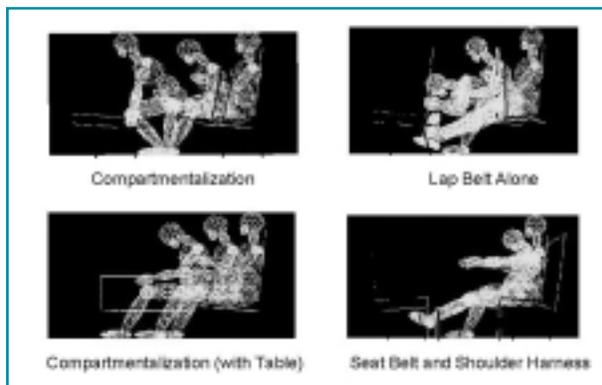
**Dynamic Sled Testing of Passenger Seats** - The Volpe National Transportation Systems Center has been supporting the FRA in analyzing the crash responses of high-speed and conventional-speed passenger trains. The analyses have been performed using computational tools developed for the automotive industry. The experimental data obtained during this test effort provide a better understanding of the occupant response and seat performance during the secondary impact in the event of a train collision. The data also validate the simulation results over the range of variable seat parameters analyzed with the present computer model.



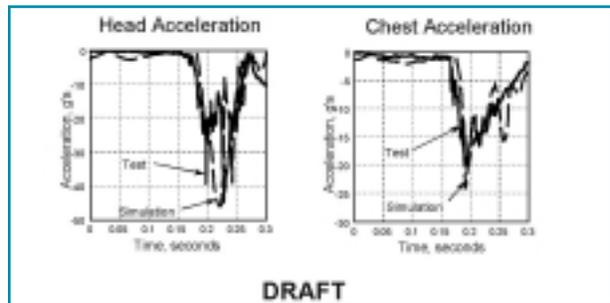
**Sled Testing of Passenger Seats**

During 1996, the first in a series of tests was performed by MGA Research Corporation at its automotive test and proving grounds in Burlington, Wisconsin, and at its test facility in Detroit, Michigan. The test effort was conducted in cooperation with Amtrak, which provided the seats, and the National Highway Traffic Safety Administration (NHTSA), which provided the test dummies.

Tests were conducted using traditional passenger seats to evaluate their performance under static and dynamic loading conditions. Quasi-static tests were



**Occupant Protection Strategies**



**Test Results Vs. Simulation**

conducted to establish the load-deflection characteristics of the seats. Dynamic tests of selected collision conditions were conducted with instrumented dummies to evaluate the collision performance of the seats and to verify the analytic simulation tools.

Injury criteria measured and calculated included head injury criteria, chest deceleration time, axial compressive neck load, and femur load. The injury criteria for the dynamic tests were within the acceptable human tolerance levels as specified in NHTSA and Federal Aviation Administration standards.

The quasi-static testing indicated the seats were sufficiently strong to withstand the occupant loads predicted from the computer simulation. However, under dynamic loading conditions, the seat attachments were prone to failure, particularly at the wall mount.

These test failures possibly were due to the inertial effects of the seat which were not present during the static tests.

The dummy's head and chest deceleration time histories and injury criteria from the dynamic tests were compared to the results of simulations corresponding to each of the dynamic tests. The comparisons demonstrate reasonable agreement between the analytic predictions and the dynamic test results, given the variability of the effective stiffness of the seats under different loading conditions.

## RESEARCH STATUS

Current projects include the following:

**Cab Car Crashworthiness Study** - The objective of this study is to determine an effective means of protecting the cab car operator and occupants during a collision. Cab car structural crashworthiness strategies employed worldwide, particularly those employing crush-zones, will be reviewed.

**Crash-Energy Management Design Study** - The objective of the Crash Energy Management Design Study is to demonstrate the feasibility of designing and implementing an energy management system into an intercity train. The energy management system shall substantially improve collision safety for train passengers.

**Over-Ride and Lateral Buckling Study** - The objective of this task is to determine strategies for

preventing car-to-car over-ride and trainset lateral buckling during train collisions.

**In-Line Collision Test Planning** - Develop plans for tests to measure data for comparison with analytic models of car crushing and of train collision mechanics and tests to measure the secondary collision environment during in-line train collisions. The tests being planned are arranged to measure the behavior of main structure elements of passenger cars under failure conditions, and to measure the crushing of the car and gross car motions (i.e., over-ride and/or train buckling) during a collision.

**Lap and Shoulder Belt Feasibility Study** - The principal objectives of this study are to develop the design requirements for an intercity and commuter passenger coach seat which incorporates lap and shoulder belts, to develop an engineering model (proof-of-concept) design for a seat which meets these requirements, to estimate the associated costs, and to estimate the potential reduction in effectiveness of seat and lap belts owing to misapplication.

## FUTURE RESEARCH

Research planned for the next several years includes, but is not limited to, the following areas:

- Evaluate the influence of occupant size on the likelihood of life-threatening injury.
- Determine the performance of current passenger equipment when struck in the side by a highway vehicle.
- Determine the performance of current passenger equipment during derailment and rollover.
- Evaluate single-car oblique collision dynamic test using existing and new data.
- Conduct passenger secondary collision parametric study.
- Conduct cab car operator secondary collision protection study.
- Conduct single passenger car oblique collision dynamic test to measure the trajectory of the cars during the collision, to measure the secondary collision environment, and to measure the crushing of the complete car structure for new cab car design.

- Conduct first single passenger car in-line collision dynamic test to measure the trajectory of the cars during the collision, to measure the secondary collision environment, and to measure the crushing of the complete car structure.

# **HIGH-SPEED RAIL SAFETY ASSURANCE PROGRAM**





## HIGH-SPEED RAIL SAFETY ASSURANCE PROGRAM

### SUMMARY

The FRA has been working since 1988 to ensure that all proposed high-speed ground transportation (HSGT) projects will result in a very high level of safety for riders and the American public in general. For the last 5 years, the goal has been to anticipate regulatory needs, then work toward ensuring the necessary research results are in place, and finally to facilitate timely and effective rulemaking that does not needlessly inhibit technology advancements. One key to assuring the safety of new technology applications is to undertake system level analysis commonly referred to as system safety analyses. During the last 5 years two projects, a maglev system in Florida, the Transrapid, and a high-speed train in Texas, the Texas TGV, were addressed by the FRA in this manner. For both projects, the FRA practiced what can be referred to as project-accompanying-safety assurance. Teams of FRA and FRA support personnel have worked with project teams to minimize risk at the system level in the design process by identifying all system risk elements that can be “designed out of the system”. When this was not possible, appropriate mitigation methods to control the risk have been pursued. This total system approach is now also being adopted in FRA’s traditional areas of regulation for intercity freight and passenger service.

To identify key research areas for HSGT, the FRA enlisted the help of the National Academy of Science’s Transportation Research Board to convene workshops into the safety-related research needs for high-speed ground transportation in 1991 and 1993. These workshops brought together industry, labor, and academia in a climate of collaboration to reach consensus on important topic areas to focus limited federal research dollars.

As a result of these workshops and ongoing input from other stake holders and FRA participation in relevant TRB and other industry sponsored standing committees, key research topic areas such as collision avoidance, accident survivability, and emergency preparedness were identified and well



Eurostar Traveling through Belgium

developed when the FRA began regulatory considerations in these areas.

Today, more than ever, the goal of this work is to continue to develop the necessary basis for timely, efficient and effective rulemaking by the FRA for HSGT systems. With the approaching delivery of Amtrak’s new high-speed Trainsets for 150 mph operation on the Northeast Corridor in 1999, and the move towards 125 mph operation on New York State’s Empire Corridor and other state initiatives towards high-speed rail, the need is real.



FRA Project Team Reviews TGV Power Car Safety Design Elements at GEC Alsthom’s (now Alstom) Locomotive Assembly Plant.



GEC Alstom's TBL2 Automatic Train Control Test Car

As part of the ongoing effort to review underway and planned research, a formal reassessment of the High-Speed Ground Transportation Safety Program is planned for FY 1999. This will be an internal review and will be based upon a format of a structured program risk analysis to determine how well current research projects and priorities are focused on current and future potential research needs.

The trend of incorporating broad aspects of the program into ongoing track, vehicle, and systems research and development will continue. Specifically, those areas where the overlap between a high-speed focus and the “traditional” railroad focus has become significant will continue to be moved into the latter area to avoid any duplication of effort. Areas unique to high-speed operations or not covered under other programs but which are necessary for ensuring the safety of high-speed operations will be continued or expanded. Some examples of these types of projects include items that play heavily in an HSGT system risk perspective such as fire safety and emergency preparedness, crash safety assurance during high-energy collisions, human factors for high-speed train operations, aerodynamics and noise generation, and platform safety. In addition, exploiting the synergies between the various FRA research initiatives will continue to be stressed.

The major HSGT issues/risk factors affecting train safety that are topics of FRA research include the following:

## Accident Avoidance

- Maintaining adequate train-to-train separation and reducing the likelihood of grade crossing accidents and right-of-way intrusion via signals and train control, operational scenarios, and human factors considerations.
- Maintaining adequate track and right-of-way quality for type of operation(s) via construction standards, maintenance and inspection standards, and track condition implications on vehicle/guideway dynamics.
- Reducing vehicle-caused derailments by addressing train handling, train make-up, and vehicle suspension condition implications on vehicle/guideway dynamics.
- Minimizing the environmental and operational impacts of EMF, noise, aerodynamic/platform safety.

## Accident Response

- Ensuring passenger and crew safety in the event of an accident
  - Crash survival - structural and interior layout designs
  - Post-crash survival - fire safety and emergency access
- Ensuring adequate evacuation plans and emergency response
  - External - derailment sites and the general population
  - Internal - passengers and crew

The HSGT Safety program is focused on accident avoidance and response in three major areas outlined in the remainder of this section. These are:

- System Level Issues
- Passenger Vehicles
- Track and Right-of-Way

## SYSTEM LEVEL ISSUES

### SYSTEM SAFETY AND EMERGENCY PREPAREDNESS

In December of 1993, a report entitled, *Recommended Emergency Preparedness Guidelines for Passenger Trains*, was published and has since served as a valuable tool for Amtrak and all operators of commuter rail systems. The information contained in this report also has served as an important basis for developing comprehensive passenger equipment safety standards that include emergency preparedness and response issues for high-speed ground systems. Staff familiar with this work has participated in the emergency preparedness working group of the safety standards development initiative of the FRA Office of Safety. In a related effort, the FRA has consulted with the Fire Protection Training Division of Texas A & M University as it developed course material in conjunction with Amtrak for a passenger train emergency response course that includes actual passenger cars as part of the training initiative.



Evacuation Drill in Pennsylvania Station, New York City

### RESEARCH STATUS

Support in this area, underway since 1989, has included a review of two now-terminated projects -

the German Transrapid System (Florida) and the French TGV (Texas), as well as the X2000, ICE, and Talgo trains deployed for test and revenue demonstration service on the Northeast Corridor and other Amtrak intercity lines. The research in this area realized the following results:

- Developed an Emergency Preparedness Guidelines Report for Passenger Trains based on previous work on Federal Transit Administration projects performed at the Volpe Center.
- Worked with Amtrak and the Texas Transportation Institute at Texas A&M to develop a course on Passenger Train Emergency Response.
- Initiated a 3-Phase Fire Hazard Analysis for U.S. Passenger Train Systems and completed Phase-1: Evaluation of Current Materials in Bench-Scale Tests.
- Monitored research on electromagnetic fields and potential associated health effects.
- Initiated development of corridor risk analysis methodology to prioritize train control deployment.
- Documented vital software validation and verification methods used worldwide in safety critical industries (nuclear, health, and transportation).

### KEY FINDINGS

The effects of highly automated systems on human operators and the resulting training and qualification implications for operators have been determined.

### FUTURE RESEARCH

Safety analysis support will continue for the recently placed order for the new high-speed Northeast Corridor trainsets by Amtrak, and the FDOT/FOX high-speed train project utilizing TGV technology in Florida as well as the continuing Talgo technology demonstrations in the Pacific Northwest.

## AUTOMATION LEVELS/METHODS AND OPERATOR RESPONSE

Refer to Human Factors section for more details.

**Advanced Train Control Systems and Accident Avoidance** - Advanced Train Control Systems use a multiplicity of software-driven, radio-frequency data distribution transceivers, transponders, sensors and actuators in many wayside and train-borne railway signal and control systems. These software-driven components present critical interfaces among signals, communications, and train control functions. Although digital automatic control systems offer potential increased capability, availability, dependability, and cost-effectiveness, they are also more complex. Furthermore, they consist of a combination of hardware and software that are interconnected in complex networks and process complex software procedures. Increasingly complex interactions among these functions have the potential to create unknown and potentially unsafe failure modes. Research is being conducted to understand these failure modes and to develop procedures for validating, verifying, inspecting, testing, and evaluating the safety of these devices and systems. In September 1995, two reports, *Safety of High Speed Ground Transportation Systems: Analytical Methodology for Safety Validation of Computer Controlled Subsystems: Vol 1. State-of-the-Art and Assessment of Safety Verification/Validation Methodologies* and *Safety of High Speed Ground Transportation Systems: Analytical Methodology for Safety Validation of Computer Controlled Subsystems: Vol 2. Development of a Safety Validation Methodology*, were published. In May 1993, *Verification Methodology for Fault-Tolerant, Fail-Safe Computers Applied to Maglev Control Computer Systems* was published.

This project area is intended to lead to guidelines and recommended practices for validation, verification, inspection, and testing of electrical and electronic hardware and software systems affecting train control safety.

## RESEARCH STATUS

**Fail-safe System Performance and Validation Requirements** - The development and usage of microprocessors and computers has resulted in sig-

nificant increased use and reliance on microprocessors-based products in numerous safety critical signal, control, and interlocking systems. To satisfy railroads' safety, reliability, and maintainability concerns of this new technology, Working Group E-3, *Signal Controls and Safety Assurance Applications*, of the Association of American Railroads (AAR), Communication and Signal (C&S) Division (now part of AREMA) has focused on the development of guidelines, specifically Section 17 of the AAR C&S Manuals, *Quality Principals, Software Based Equipment*. The objective of this guideline is to develop a quality assurance program that, if implemented comprehensively, will assure safety, availability, and reliability of railroad operations. As of January 1, 1998, the AAR C&S Division manuals and committees have been transferred to the American Railway Engineering and Maintenance-of-Way Association (AREMA).

In addition to the AAR and AREMA efforts, the IEEE Vehicular Technology/Rail Transit Vehicle Interface Standards Committee established Working Group 2 to develop the minimum set of performance and functional requirements necessary to achieve an acceptable level of safety, performance, availability, and operations for Communications-Based Train Control (CBTC) systems. The goal of the standard is to enable transit agencies to streamline their CBTC procurement, enabling suppliers to focus their development efforts, and minimize the amount of new design required for each new application.

The IEEE Vehicular Technology/Rail Transit Vehicle Interface Standards Committee also established Working Group 4 to develop a draft standard for the verification of safety for process-based systems used in rail transit control. The introduction of integrated circuits, microprocessors, and software has increased the complexity of safety-critical systems potentially beyond the ability of traditional analyses to verify their safe operation in the event of hardware component failures and software errors. The purpose of this standard is to provide agreed upon verification procedures and analyses which, if implemented comprehensively, will verify the level of safety assurance achieved in a given system is adequate to meet the stated safety objec-

tives. FRA staff have actively participated in and contributed their technical expertise to the standard development efforts of the AAR and IEEE.

### KEY FINDINGS

One safety validation and verification methodology under consideration by the FRA uses a three-layered approach for dealing with hardware and software faults. Validation essentially uses fault avoidance techniques during the specification, design, and development phases to ensure that inherent faults do not exist. Fault removal techniques are used during testing and verification to eliminate faults that were not avoided. Fault-tolerance techniques may be used in operation to detect and recover in real-time from those faults that are not eliminated by fault avoidance and fault removal techniques.

To date, the IEEE draft standard has focused on the analysis required for verification. It includes a methodology for intrinsic fail-safe design, checked-redundancy, N-version programming, diversity and self-checking, and numerical assurance. There are three levels of analysis - conceptual, functional, and implementation. The conceptual portion of the analysis is where differences occur in the way analyses are performed. This is evident in the safety assurance concept and the dependent factors. The safety of a system is dependent on the correctness of software. Suppliers are required to show that software is free of errors that will not cause unsafe failures. However, there is no definitive means of ensuring that software is correct, or to show that there is a boundary on the number of software errors. Recognizing that there is a set of failure modes that will likely always exist because software will likely never be correct, the question remains how we can make software fail-safe.

Typically there is a fine line between a fail-safe calculation and shutting down the system. Availability and reliability must be balanced. The use of computer off-the-shelf (COTS) operating systems are cost effective, but they are not developed under the same quality assurance standards as safety-critical software. The issue is how to implement reliable computing using unreliable components, and, how to maintain distributed systems without errors.

Recognizing that hardware and software are expect-

ed to fail at some time during the system life, and that a system must be able to tolerate these faults while maintaining normal operations, or in the exceptional worst case scenario, by failing in a safe manner. The goal is for redundancy to be managed in such a way that a vehicle can be dispatched reliably with failures in order to achieve greatly improved availability, dependability, and system productivity with a minimum number of vehicles.

### FUTURE RESEARCH

Future work in this area will consist of continued support to industry standards development and, where necessary, support to regulatory actions. Safety analyses related to the Next Generation High-Speed Rail Positive Train Separation and Positive Train Control development initiatives will be conducted (see Part B, Next Generation High-Speed Rail). The applicability of the validation and verification methodology being developed will be demonstrated initially on a laboratory model and later on a real control system such as a Positive Train Control system. This demonstration will be monitored by the AREMA C&S Division Technical Committee E. Other possible directions for work in this area may include analysis of other critical automated systems such as remote/automated brake inspection systems and remote monitoring of truck hunting that may lead to unstable vehicle guideway dynamics at high speed.

**Environmental, Safety, and Health Effects of Electromagnetic Fields and Radiation** - With the advent of high-speed rail (HSR) improvements and upgrades in rail infrastructure, vehicles, and communications and control technologies, the U.S. railroad environment is rapidly changing. Increased electrification, automation and reliance on distributed communication and control systems for positive train control systems are changing the rail operating environment. Expanded rail electrification and HSR systems and services in congested corridors promise improved speed and energy efficiency with added environmental benefits. However, lingering public concern with potentially adverse health effects of electromagnetic fields (EMF) and radiation (EMR) must be proactively addressed to successfully deploy new rail technologies.

Extremely low frequency (ELF) EMF near the power frequency (60 cycles and harmonics), and broad-band radio frequency radiation (RFR) can become of concern to safe rail operability due to electromagnetic interference (EMI) and lack of sub-system compatibility (EMC), as well as to the health and environmental quality for rail workers, passengers and the public. EMF and EMR are a continuing concern in advanced rail and transit transportation. They were a major issue in recent litigation on the Northeast Corridor Improvement Project, and key concerns in previous Florida Maglev and Texas HSR proposals and environmental assessments.

In 1990, in response to Congressional and public concerns, the FRA initiated an EMF research program in order to characterize EMF emissions associated with conventional, advanced, and prototype rail systems, such as HSR and maglev, and to identify and assess potential health and safety effects and cost-effective options for EMF control, mitigation, and regulation. The Volpe Center has managed this program for the FRA since 1990 as an integral part of the safety analysis and regulatory development support for maglev and other advanced rail technologies, in partnership with EPA and DOE Argonne National Labs, and with contract support. The EMF research program also focused on potential operational safety impacts of EMI and EMC. Research findings have informed and supported rail development planning, environmental impacts, and safety regulatory development. A data base resulted from an EMF survey program to enable comparison of rail technologies and aid in preventing or mitigating potential environmental, safety, and health (ESH) hazards through siting, design, and engineered materials, or through operation and exposure management.

## RESEARCH STATUS

Over the past 5 years, accomplishments in this area have included the following:

- Developed a portable EMF test instrumentation and a tailored test protocol for a comprehensive dynamic characterization of the rail EMF system and environment.
- Performed an extensive EMF survey of and developed an EMF database for existing and

emerging rail and transit electro-technologies and systems (control centers, electric substations, passenger stations, and under and near the catenary or third rail in locomotive cab and passenger cars) including the TR-07 German maglev, the French TGV, the Northeast Corridor (conventional diesel-electric, electrified 25 Hz and 60 Hz portions, and the Metro-North and North Jersey Coast transit), and transit systems in Washington and Boston (light rail with third rail D.C. or catenary systems, electric trolley).

- The EMF dynamic characteristics of maglev and emerging HSR systems were compared with existing transit and electrified rail systems, and with other common environmental (home, work, and office) EMF sources.
- Comparative data on EMF characteristics of each transit and rail electro-technology were developed, enabling designers and operators to identify and prevent or mitigate any potential safety hazards or public health concerns.
- In the absence of Federal EMF guidelines, development of draft regulatory guidelines for EMF emissions and exposure of passengers, public, and personnel from maglev and HSR systems was undertaken for proposed U.S. applications (such as the Orlando Maglev Project, Texas TGV, the Northeast Corridor Improvement Project (NECIP), Amtrak's NEC HS trainsets, and the FDOT/FOX Project.)
- The National Maglev Initiative program (1990-1994) also addressed design and mitigation options to minimize passengers' exposure to EMF with active or passive magnetic shielding. Such studies included the maglev technology and system concept definition; General Electric Corporation assessed the cost and performance impacts of active and passive shielding options for superconducting maglev designs; Foster Miller, Inc. demonstrated a novel high temperature superconductor shielding concept, offering active magnetic field control options for maglev; and Intermagnetics General Corporation (IGC) explored modeling of stray fields and magnetic shielding options for maglev using superconducting magnets.

- Thirteen published reports on EMF issues and findings and chapters on EMF/EMI/EMC assessment, mitigation, and safety guidelines for the operating environment of high-speed ground transportation systems have resulted from this research program, as well as expert support to other programs (e.g., work rules, electrical safety, interference-free design of GRMS, and the Environmental Impact Statement for NECIP).

### KEY FINDINGS

- New rail systems did not exhibit unusual EMF intensity, but have unique variability in time and space, and frequency spectra (signatures) typical of the electro-technology employed.
- The German TR-07 maglev technology did not produce unusually strong EMF and costly shielding or other active field management was unnecessary.



Phased Array - Maglev Noise Monitoring at Emsland Test Facility in Germany

### FUTURE RESEARCH

**Environment, Safety and Health Effects of Broad Band EMF/EMR** - Continuing monitoring

and adoption of national and international research, policies, regulatory standards and control options to address ESH issues for new technology developments (FDOT/FOX, HSST maglev, and introduction of PTC and Global Positioning System-aided advanced train control system), to ensure effective monitoring, prevention, and mitigation of potential ESH effects.

**Evaluation of EMF/EMR** - Basic research and development to aid the improvement and electrification of transit, commuter, and high-speed rail will continue. Evaluation of the EMF associated with high-speed rail operations, including Amtrak's American Flyer and FDOT/FOX also will continue. The focus of this effort will be on EMF/EMR modeling and measurement and on cost-effective engineered options for prevention, mitigation, and control in the rail environment.

**Electrical Systems Safety and EMI/EMC** - New technologies such as microprocessor-based controls, wayside distributed and onboard computers and sensors, the Global Positioning System, and wireless data transmission systems such as spread spectrum radio, are being introduced by the railroad industry. The circuitry in these systems is extremely sensitive to low-power-conducted-and-radiated EMI. EMC for safety-critical components and subsystems for communication, navigation, location, and control must be assured for safe rail operation. These technologies must be certified for safe operability for the full range of electromagnetic frequencies and sources found in an increasingly radio-polluted operating environment. New rail systems and technologies will be evaluated to ensure that they comply with industry-accepted best practice and EMI standards and to provide EMI/EMC/EMF characterization, test, and mitigation support as required.

**Identification of Applicable Technical and Safety Standards** - In order to comply with PL 104-113, The National Technology Transfer and Advancement Act of 1996, it may be necessary to establish a technical standards working group under the Railroad Safety Advisory Committee to identify, select, adopt, or adapt appropriate existing consensus or other professional organization technical personnel and public exposure safety standards for EMF and EMR emissions.



## PASSENGER VEHICLES

---

**Collision Avoidance and Accident Survivability**

Refer to the Train Occupant Safety Section for more details.

**Fire Safety** - Refer to the Train Occupant Safety Section for more details.

**Advanced Braking Systems** - Refer to the Rolling Stock Section, Equipment and Component Structural Integrity, for details on this topic.

## TRACK AND RIGHT-OF-WAY

---

**Track Structures at High Speed** - In the area of track standards, a new initiative is underway to place two instrumented wheelsets under Amtrak's Track Geometry Car No. 10002. The objective of this research is to tie together known track geometry data with wheel/rail force data (via the instrumented wheelsets) and ride quality data (via instrumentation from accelerometers provided by the Next Generation High-Speed Rail Program) to develop realistic performance-based track geometry standards for high-speed operations. Track maintenance history and inspection results will also be a part of the overall data analysis/correlation efforts. This work is part of a cooperative effort with Amtrak to better understand the interactions between high-speed operations and track quality and follows up the various efforts completed during the demonstrations of the Swedish X2000 and the German InterCity Express (ICE) trains on the Northeast Corridor.

In the area of guideway strength, the major initiative is a multi-year program to better understand the phenomenon of track shift, a unique lateral movement of track under high-speed operations be it 200 mph stiff trucks or 150 mph steerable trucks. The report, *Safety of High Speed Ground Transportation Systems: Track Lateral Shift: State-of-the-Art Review*, was published in February 1996.



Photograph courtesy of Bombardier, Inc.  
Transportation Equipment Group

Model development leading to a better understanding of the safety issues is currently underway and the analysis should be complete in FY 1998. This is discussed in more detail in the Track Lateral Shift for HSR Applications later in this section.

### RESEARCH STATUS

- Developed initial guidelines for high-speed track structures in terms of stability under high thermal and mechanical loadings.
- Initiated development of innovative track geometry measurement techniques based on correlations between ride quality measures and wheel/rail force measurements.
- Completed a draft report on a review of safety issues related to the operation and maintenance of electrified railroads.

All support in the safety area is oriented toward the realization that there are potentially serious safety implications of passenger service operating at much higher speeds and operating in mixed traffic and/or utilizing innovative technologies. The safety review of the Amtrak High-Speed Trainset Specification for the procurement of 18 (now 20) high-speed trainsets is consistent with this reality and is an example of multi-disciplinary safety analysis support of high-speed ground systems.

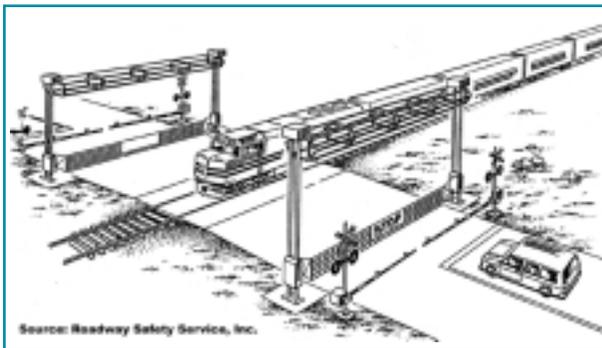
The Office of Research and Development provided guidance to the Office of Safety and Amtrak in areas such as brake system status monitoring, brake disk temperature limits, truck safety parameters, and structural crash energy management. A more in-depth research project was then conducted in the area of crash energy management design and interior configurations such as seat belt options. Work is continuing in the area with more detailed analyses of crash energy management issues and seat securement systems.

### KEY FINDINGS

Because high-speed operations are more likely to automate safety-critical functions, and to rely on advanced communications methods, confidence in the reliability of the equipment and methods is critical.

### FUTURE RESEARCH

Track analysis and further model development is planned to continue through FY 1998. Work will also go on in the area of more detailed analyses of crash energy management issues and seat securement systems.



**Safety of Mixed Operations can be Assured Through a Detailed Safety Analysis and Risk Mitigation Plan**

Drawing Courtesy of Roadway Safety Service, Inc.

### **Shared Rights-of-Way and Mixed Operations -**

With the limited availability of new rights-of-way and the high cost of acquiring and building them, when funds are available, the importance of utilizing existing rights-of-way or trackage is key to developing realistic high-speed passenger service alternatives in the United States. However, utilizing rights-of-way or trackage for multiple purposes requires an understanding of the significant potential safety issues and the viable options for their resolution. To facilitate the safe adoption of multiple uses of rights-of-way corridors or trackage, the FRA has undertaken several studies in this topic area.

### RESEARCH STATUS

The following reports were completed over the last five years:

*Safety of High Speed Guided Ground Transportation Systems: Shared Right-of-way Safety Issues-* This report presents the results of a systematic review of safety issues associated with an HSGT system sharing the same right(s)-of-way as other mode(s) of transportation such as automobiles, mass transit systems, commuter rail, intercity passenger rail, freight trains, pipelines, or transmission lines. The report also notes specific risk mitigation options for various operational scenarios.

*Safety of High Speed Guided Ground Transportation Systems: Intrusion Barrier Design Study -* This report documents the results of research into anti-intrusion systems that would perform the function of preventing a derailed railroad car, an errant highway vehicle, or some type of dislodged load from intruding into the operating envelope of an adjacent high-speed line.

*High-Speed Passenger Trains in Freight Train Corridors: Operations and Safety Considerations, December 1994 -* This report presents the results of a study into operational and technical issues likely to be encountered when planning for high-speed rail passenger service on corridors that currently carry freight or commuter traffic. An analysis in the report establishes a safety performance target based upon present intercity rail operations.

### KEY FINDINGS

- Shared Rights-of-Way are feasible for HSGT.
- Risk can be adequately controlled with proper scenario development and mitigation efforts.
- Mitigation against accident occurrence is more effective than consequence mitigation.
- Development of specific mitigation options may require further development.
- Design and construction of effective barriers is feasible for HSGT ROWs.
- Some barrier designs are more cost effective than others and some designs should be abandoned.
- Although mixed operations are feasible for site-specific analyses, these should be used together with appropriate organization, economic, and environmental studies to evaluate actual corridors.

## FUTURE RESEARCH

Concern for rights-of-way safety has recently expanded to include security and integrity issues. Research is planned to address the topics of innovative rights-of-way monitoring systems for items such as bridge integrity, wash out conditions, trespassers, and a variety of potential malicious acts that could compromise right-of-way integrity.

Secondly, aerodynamic operational issues resulting from high-speed train development or expansion on existing corridors will be studied. Specifically, window glazing standards will be reviewed and potential safety issues for passengers on platforms of run-through stations will be documented.



Advanced Planning Will Avoid Unsafe Platform Situations

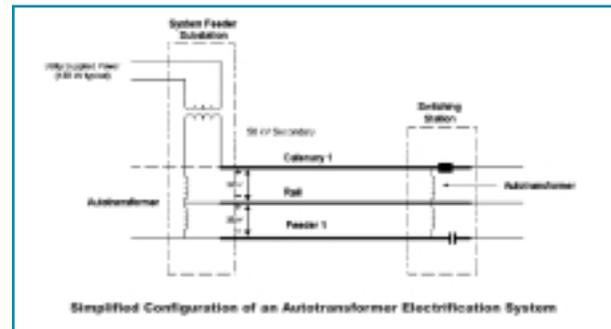
**Electrical Safety** - For high-speed rail transportation systems, electrification is often the most efficient method for supplying traction energy to train-sets. Such electrified systems will require substations for processing electric-utility-supplied power, wire networks for electric power distribution along the right of way, means for transferring this wayside power to moving trains, propulsion control of onboard traction motors, and train line power for control and passenger comfort system loads.

Guidelines are required for newly emerging or proposed systems to ensure that the construction, operation, and maintenance of electrified systems will not jeopardize the safety of the general public, passengers, or system employees. The FRA, with support from the National Traction Power Committee (NTPC), has undertaken several studies in this topic area. The NTPC is an organization made up of eleven electrified railroads whose purpose is to enhance and sponsor the exchange of operating and

safety procedures relating to the traction power in the transit/railroad industry.

## RESEARCH STATUS

FRA/NTPC - Research Needs /Identification of Key Safety Issues Coordination. The FRA and NTPC have had discussions and shared operational and research knowledge in the areas of electrical safety. The FRA has actively participated in NTPC quarterly meetings, and the NTPC and FRA have jointly defined railroad-specific electrical safety research needs.



Simplified Configuration of an Autotransformer Electrification System

*Safety Considerations with Railroad Electrification: A Preliminary Review and Assessment, Draft Final Report, June 1996.* This report presents the results of a study of safety considerations and analysis of electrified systems. The analysis was directed at identifying and evaluating electrically-related hazards that could be present in such systems for advisory use by new as well as existing operators.

*Development of Model Work Rules for Electrified Railway Systems, Draft, March 1996.* As part of the preliminary safety study of electrified railroad systems, an initial outline of a prototype set of electrical operating instructions (safety work rules) was developed. These safety work rules were based upon a review of numerous industry standards, available railroad electrical operating instructions and safety rules, government regulations, and other relevant standards. The information presented in this document is for advisory use only by the railroad industry.

## KEY FINDINGS

- NTPC serves a valuable function of maintaining and enhancing electrical safety on existing electrified systems and serves as corporate memory on this topic.
- Hazards from electrified railway systems can be maintained at acceptable levels by appropriate system and equipment design and through the development and use of safety rules and safe work practices.
- Foreign electrical safety standards are not necessarily equivalent to U.S. electrical safety standards. Coordination groups between U.S. and foreign standards organizations are forming to harmonize the differing standards.
- Government regulations and industry standards for electrical safety were general purpose and electric utility specific, not railroad specific.

## FUTURE RESEARCH

The FRA, Office of Research and Development will continue to maintain a current understanding of electrical safety issues as they relate to high-speed operations.



Catenary Worker on Structure Over Train



# RESEARCH AND DEVELOPMENT FACILITIES AND TEST EQUIPMENT





## TEST FACILITIES

### SUMMARY

The anticipation of the introduction of new, high-speed trains (150 mph) in the United States operating environment brings with it the need for verification testing before these trains can be placed into revenue service. Tests will be conducted to verify the performance of their mechanical and electrical systems, determine ride quality, examine the system durability, and ensure that all safety features operate as designed as well as other important factors. A safe and efficient location is needed to accomplish this task and detailed test plans must be developed and implemented.



RALES Cab and Motion Base

Development of a safe and efficient high-speed rail system requires a dedicated testing facility and comprehensive testing programs. As new and innovative ideas and products are developed, testing will be undertaken to analyze and evaluate their worthiness.

The Department of Transportation's Transportation Technology Center (TTC) site includes 48 miles of

railroad track devoted to testing all types of rolling stock, track components, signal, and safety devices. These tracks are used for track structure and vehicle performance testing – track and service worthiness, life-cycle and component reliability, and ride comfort. The TTC also has several one-of-a-kind laboratory test facilities used for evaluating vehicle dynamics and structural characteristics.

The Research and Locomotive Evaluator Simulator (RALES) facility is located on the campus of the Illinois Institute of Technology (IIT) in Chicago, and is housed within the ITT Research Institute. It comprises a complete locomotive cab (with the industry-standard control stand) mounted on a motion-simulation base. RALES provides a high-fidelity simulation of the in-cab experience of a locomotive engineer, including a projected display of real-world track (originally from 16mm movie film); an out-the-side window view of the cross ties (used by engineers to judge very low speeds); and a sound system that generates engine, brake and track noises.

The RALES facility became operational in 1984 and was based on human factors requirements developed by the FRA. An extensive upgrade was completed in 1994 that replaced the film projector with laser-disc video as well as new computer hardware. In its present configuration, RALES is limited to simulation of trains operating at 80 miles per hour, or less.



RALES Control Room

The FRA maintains a significant stock of equipment, including two FRA-owned railroad vehicles, T-6 and T-10, that are used to support track research and safety inspections. These vehicles were developed under the FRA track research program and are the product of instrumentation and data processing advancements that are uniquely applicable to the railroad environment. In the past, the FRA Office of Research and Development, has operated numerous research vehicles to develop technologies pursuant to its mission, particularly for track inspection and rail flaw detection, and for collecting data for vehicle/track interaction studies.

T-6 is the only remaining operational FRA research vehicle currently used to support the Gage Restraint Measurement System (GRMS) consists. The T-6 was built as a hospital car in the 1950s and began its R&D service as a special test vehicle used in track geometry and safety enforcement until the mid-

1970s. It was decommissioned for a number of years, and then reactivated in the mid-1980s as the developmental test bed for the GRMS. The T-6 was also used for developing rail flaw detection systems; collecting track and vehicle data in support of track strength measurements, collecting data used in vehicle dynamics analysis and derailment studies; and collecting data on vehicle track interaction (instrumented wheels).

Currently, the T-6 is used to support GRMS testing activities and functions - in a limited way, because of its age - as a research platform for any additional over-the-road test requirements. Future work scheduled for T-6 will include collecting over-the-road data and evaluating the track analyzer, acting as a test platform to evaluate software and hardware for data alignment procedures tests, and providing support as a data recording vehicle, or loading vehicle, for track stiffness measurements.

## RAILROAD TEST TRACK UPGRADE

### RESEARCH STATUS

The TTC is operated by the Association of American Railroads (AAR) Transportation Technology Center, Inc. (TTCI), a wholly-owned subsidiary, of and under a care, custody, and control contract with the FRA. It consists of a variety of test tracks and facilities including a 13.5-mile railroad test track (RTT). The National Railroad Passenger Corporation (Amtrak) and the Florida DOT are planning to operate trains at speeds of 150 and 200 mph, respectively. This presented a need for a test facility to evaluate safe operations/performance requirements before these high-speed trains were placed into revenue service.



### Installing New Rail in the RTT

In July 1993, the FRA initiated work to upgrade the RTT to allow for a broader range of testing variables. The Volpe Center and Parsons, Brinckerhoff, Quade & Douglas (PBQD) supported the FRA in this effort. Based on the RTT condition study, Amtrak's high-speed operational needs and funding considerations, an RTT upgrade program was developed. The modified track configuration will permit evaluation of the safety, performance, and reliability of prototype high-speed passenger equipment at speeds up to 165 mph. The program was overseen by a working group from the FRA, AAR, Amtrak, the Volpe Center, and PBQD with financial and technical support in partnership with the private sector.

At the start of the upgrade, the RTT consisted of 20-year-old, 13.5 miles of closed loop track of both jointed and continuously welded rail with conventional cut spikes and softwood ties on slag ballast. The loop consisted of four 50-minute right-hand curves ranging in length from 1500 to 15,900 feet, a 50-minute reverse curve with a tangent distance of 100 feet between the curves, and spiral length ranging from 600 to 2,306 feet. With the combination of curves and spirals, it is possible to determine equipment ride quality and maximum force levels developed at the wheel/rail interface over a range of geometric conditions. The existing Style 5 catenary was supported and registered by a single pole and catenary support structure with a maximum span length of 210 feet. The tension in the conductors was maintained by movable balance weights at each end of the catenary section. Both the track structure and the catenary showed signs of wear, which was expected, since they have been in use since the 1970s.

Improvements to the RTT were divided into two phases and began with realignment of a reverse curve from 50' to 1°15'. This would allow for operation at greater cant deficiencies and a longer tangent distance between two curves. The existing jointed rail was cropped and welded and turnouts were either eliminated or repaired. The worn or



### Installing Concrete Ties

damaged catenary part was repaired and two carrier wire phase breaks were installed. The second phase, conducted in 1997, consisted of replacing the soft wood ties with concrete ties except for a wood tie section consisting of 800 feet of the existing soft-wood ties with cut spikes, 850 feet of existing soft-wood ties with an elastic fastening system, 2,015 feet of hardwood with cut spikes, and 7,744 feet of hardwood ties with elastic fastening system. The ballast was undercut and granite ballast was added and the track was surfaced and aligned.

#### KEY FINDINGS

With the completed upgrade and rehabilitation of the RTT, the United States has the only dedicated

electrified test track in the world that can accommodate high-speed (165 mph) testing. This facility will be able to support Amtrak and other high-speed agencies well into the future.

#### FUTURE RESEARCH

The final improvement to the RTT will be the addition of a broken rail/open switch point detection system to ensure faults are identified and appropriate hazard train protection is achieved. This system should be fully operational prior to the initial testing of High-Speed Amtrak trainsets in the late fall of 1998.

# AMTRAK HIGH-SPEED TRAINSETS

---

Amtrak is purchasing 12 high-speed trainsets with an option for 6 more for use in the Northeast Corridor. These trains will be electric-powered.

## RESEARCH STATUS

Some of the tests which will be conducted on this new trainset will be high-speed stability, high-cant deficiency, power consumption/power draw, pantograph uplift force, phase break operation, regenerative braking performance, harmonic generation, propulsion and braking, and a 20,000-mile duration test.

## KEY FINDINGS

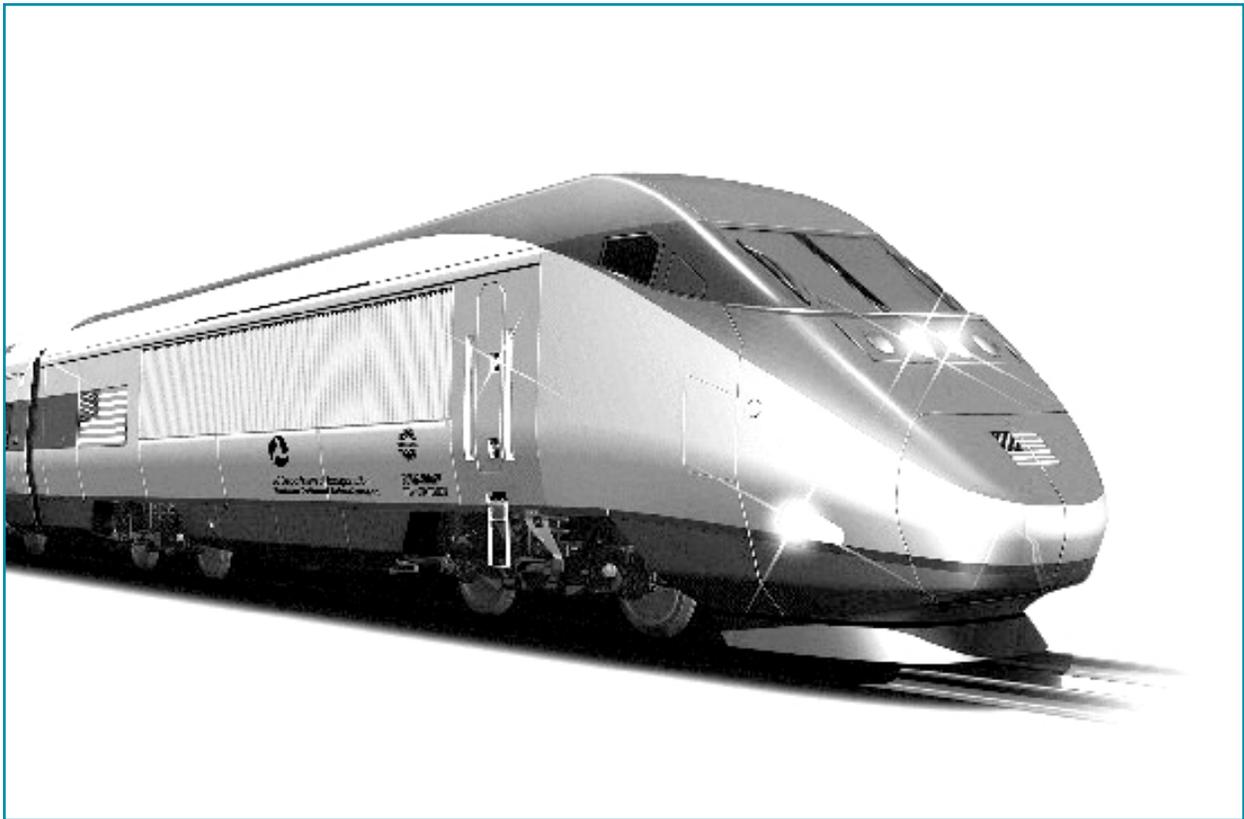
Research is yet to be performed.

## FUTURE RESEARCH

Mechanical acceptance, safety, and endurance tests will be run on the first prototype trainset beginning with contractor testing in late fall of 1998, and FRA/Amtrak acceptance testing in early 1999.



# NEXT GENERATION HIGH-SPEED RAIL





## NEXT GENERATION HIGH-SPEED RAIL

---

The Next Generation High-Speed Rail Support Program began in December 1994 in response to the Swift Rail Development Act of 1994 and the Federal Railroad Safety Authorization Act of 1994. The objective of the Next Generation program is to support the availability of modern, cost-effective technology enabling rail passenger service at speeds up to 150 mph on existing infrastructure. The Swift Rail Development Act of 1994 authorized the FRA to sponsor research and demonstrations to improve safety by reducing human and technological failures, enhance revenue generation capabilities through customer service upgrade measures such as shorter trip times, and finally, decrease capital and operating costs of high-speed rail service. The focus of the program has been to support this objective by adapting, improving, and demonstrating existing or promising technologies

that could have wide application in U. S. corridors. This focus has been re-authorized in the 1998 Transportation Equity Act for the 21<sup>st</sup> Century.

The program focuses on three main areas: track evaluation, improvement, and maintenance; signaling and communications; and non-electric motive power. Two important issues, grade crossing risk mitigation and capacity enhancement, bridge the track improvement area and the signaling and communications area. These areas have been selected to address the major cost elements inhibiting the introduction of high-speed service. In addition, the program is developing technology improvements directed at ensuring safe high-speed operations while reducing maintenance costs, improving braking performance and reducing noise and other environmental impacts.

## TRACK EVALUATION, IMPROVEMENT, AND MAINTENANCE

---

A major cost barrier to the introduction of high-speed service is the need to upgrade existing track structures to a level of uniformity and quality appropriate for high-speed operations. This often involves a significant improvement in the underlying track structure as well as improvements in rail and track geometry. Initial service will be over track shared with freight operations and the track must be maintained to support both levels of track loading. Efforts in this area are concentrating on reducing the cost of track structural evaluations and identifying specific techniques that can effectively improve the underlying track structure. Turnouts, grade crossings and bridges are traditionally areas where the abrupt change in vertical and lateral stiffness result in accelerated rates of track geometry degradation. The FRA has initiated studies into methodologies for reducing the magnitudes of the variations by placing specially designed elastomeric pads between the rail and the tie plates in the region of the transition. Early results show that vertical accelerations were significantly reduced near a bridge transition on the northeast corridor. Further studies are required to determine the long-term effectiveness of these treatments and whether the pads will withstand the harsh environment.

Track inspection is a major expense in maintaining high-speed track. Traditionally, track geometry measurements have been used to identify track requiring major maintenance activities. As track occupancy time becomes scarcer the need to

identify the exact nature and location of the track irregularity and the most appropriate maintenance procedure becomes more critical. In addition, many operators of high-speed track use acceleration data from revenue trains to help anticipate track problems before they become safety critical. These systems can be used effectively to monitor both track and equipment but are still in the developmental stages. Enabling technologies for these systems are low cost computer and signal processing equipment, global positioning systems (GPS), and wireless communications. Perhaps the most important feature of these systems is the ability to collect data without human intervention, the major cost in track geometry inspection. The GPS or differential GPS (DGPS) systems help pinpoint the subtle track geometry defects that can cause rapid deterioration of the underlying track structure when supporting both heavy freight and high speed passenger equipment.

Other areas of interest, although with no currently active projects, are high-speed turnouts, internal rail flaw inspection, and the importance of concrete versus wood ties in maintaining high-speed track stability. In anticipation of these projects the FRA has built two state-of-the-art instrumented wheelsets capable of accurately measuring the wheel rail forces resulting from track irregularities and special features such as guard rails and flange supported frogs.

## SIGNALING AND COMMUNICATION IMPROVEMENTS

Since 1994, the FRA, in partnership with state agencies, has sponsored three separate initiatives in the area of train control with the objective of demonstrating cost-effective systems capable of providing the safety similar to traditional communications and signal systems, and the business benefits of positive train control (PTC). These three initiatives are **Incremental Train Control, Advanced Train Control, and Positive Train Separation.**

### Traditional Communications and Signaling Systems

Traditional communications and signaling (C&S) systems are all reliant on relay-based track circuits. The four types are non-coded and coded AC and DC track circuits. These track circuits are the fundamental building block of fixed block train control systems such as Automatic Block Signaling (ABS), Centralized Train Control (CTC), Direct Traffic Control, and Cab Signaling. These systems are expensive to install and maintain due to the large number of components required. They are reliant on an extensive wayside equipment and circuit infrastructure including semaphores, relay huts, and ground circuits that operate the track circuits and the interlockings.

The Advanced Civil Speed Enforcement System (ACSES), currently under development for the NEC, is an example of a fixed block train control system that is being augmented for high-speed passenger service. This system is based on a wayside transponder network that will communicate with an onboard locomotive radio system. The transponders will transmit civil speed restrictions of either an entire or partial block to a locomotive's onboard computer. The onboard computer will convert this information to a cab signal for the engineer. The onboard computer will also compare the speed restriction with the actual speed of the locomotive to determine if the speed is in violation of the restriction. If a violation is occurring, the system's enforcement control will be activated. This will

entail bringing the train to a complete halt, also known as positive stop. Initially the ACSES will be installed between New Haven, Connecticut and Trenton, New Jersey. Eventually, the system will be extended to the entire Boston to Washington corridor. The system is being developed by GEC Alstom.

The ACSES will migrate the NEC from the present four-aspect continuous cab signal system to a nine-aspect continuous cab signal/speed control system. The ACSES will provide for train operations up to 150 mph with intermediate speeds of 125, 100, 80, 60, 45, and 30 mph as well as positive stop. This system is currently being tested and refined on a test bed near Philadelphia, Pennsylvania.

### Current Communications-Based Train Control Pilot Programs

In order to increase safety, operating capacity, and efficiency, railroads and railroad suppliers have instituted pilot concurrent communications-based train control (CBTC) projects. These projects demonstrate the safety and economic benefits of employing modern communications and control systems toward the implementation of moving train control systems. Some of these projects are listed below.

**Incremental Train Control** - The Michigan Incremental Train Control System (ITCS) is a joint venture between the Michigan Department of Transportation (MDOT) and Amtrak. The signaling supplier is Harmon Industries. The system is a distributed wayside-based system that is designed to function as an overlay to the existing coded track circuit system. The backbone of the system is a wayside local area network (WLAN) consisting of wayside interface unit (WIU) servers spaced every 2-6 miles. Each WIU server communicates with 5-10 WIU nodes. These nodes monitor the existing track circuitry system and report current track circuit, signal aspects, switch positions, and public grade crossing information as they are polled by the WIU servers. This information is communicated to the Office System by

means of the WIU servers. All movement authorities, temporary slow orders, and switch control information originate from the Office System and are transmitted to the wayside via a modem-wire line-modem communications link.

**Advanced Train Control** - The Illinois Positive Train Control System was originally a joint venture between the Illinois Department of Transportation (IDOT), and the Southern Pacific (SP) Railroad, with Canac International as the system integrator. The intent was to select a supplier to install a transponder-based, high-speed train control (PTC) system on a segment of the SP between St. Louis, Missouri and Chicago, Illinois. Following the merger of the Union Pacific (UP) and SP Railroads, the project was somewhat delayed as the railroad evaluated the objectives of the program and the long-term plans for the track involved. The important goal of a demonstration of a full-featured, centralized, safety-critical communication-based train control system remains. The AAR has joined with the goal of encouraging interoperability.

**Positive Train Separation** - The Burlington Northern Sante Fe and Union Pacific have been developing a PTS System. This demonstration project is being deployed by GE-Harris in the Pacific Northwest between Seattle and Pasco, Washington, and Portland, Oregon. The project participants are the Washington State Department of Transportation, Oregon State Department of Transportation, BNSF, UP, and Amtrak. The PTS system is a non-vital overlay that will operate in conjunction with the existing track circuitry system. The system is comprised of three fundamental components: (1) the centrally located server system, (2) the communications system, and (3) the onboard locomotive system. The communications system consists of a network of cables, microwave links, fiber optic cable links, and telephone circuits. This system is employed to transmit authority limits and speed limits established by the server system to the PTS equipment located onboard the locomotive as well as transmit train location information to the server system.

The major product of the demonstration is the system software and network management protocols that were developed. In addition, a number of system reliability issues can be resolved. The railroads will utilize the performance data collected during the demonstration project for deployment of potentially vital PTC systems over large segments of both railroads. Since this is a joint project, there is a significant degree of interoperability between the two railroads. This should improve the cost effectiveness of any future PTC installations. A significant incentive for developing this system was to enhance the capacity of this heavily-used track. The FRA joined the project to help assess the potential capacity improvements afforded by an advanced train control system. GE-Harris, Inc., with a funding grant from the FRA, developed a dispatching simulator for the BNSF/UP PTS system in Washington. This simulator was used to evaluate the potential benefits of adding centralized train control and more important, traffic control to the region.

## Locomotive Onboard Communication Platforms

The locomotive onboard computer systems, in addition to performing functions as train overspeed protection, are required to communicate with locomotive propulsion systems and electronically controlled pneumatic braking systems, and monitor locomotive health. The key element of onboard communications is the networking protocol linking the components. Several industry protocols that have been the subject of recent evaluation are Lontalk IEEE 1473.1, Ethernet IEEE 802.3, and Token Ring IEEE 802.5. The Conrail, NS, and CSX design team has recently chosen Lontalk IEEE 1473.1 as the onboard platform protocol in their recently released design. This protocol was chosen based on its reliability, availability, and maintainability characteristics. This is a significant step forward in the industry-wide effort for an open architecture, interoperable protocol given that Lontalk IEEE 1473.1 is employed in many of the ECP systems currently under test.

## Future Plans

As these demonstration projects and enabling technologies mature, the FRA, railroads, and suppliers will continuously monitor the lessons learned. The value of systems will be determined, from both safety and capacity enhancement.

## GRADE CROSSING RISK MITIGATION

---

Highway-Rail Grade Crossing safety is a major program area in Improving Safety. Grade crossings and the associated risk are also a major impediment to the introduction of higher-speed passenger rail service. In many of the corridors, highways cross the existing tracks more often than once per mile. A full grade separation may cost as much as \$2 million and grade crossing closure is often not an acceptable option from a local traffic planning perspective. While the risk to the highway user is not a strong function of train speed, the increased frequency of trains often associated with a new service introduction could substantially increase accident rates. In addition, the risk to passengers and train personnel, while small, does increase as the speed increases. The FRA has identified grade crossing risk mitigation as an important area for safety research and the next generation program has identified candidate technologies and innovative approaches to warning highway operators of approaching trains, and warning train operators of highway vehicles stalled or stuck at crossings. The Harmon Industries Incremental Train Control project in Michigan includes a demonstration of a pre-start health and monitoring capability using radio communications links between the locomotive and the grade crossing. The system would alert the train personnel of the crossings functionality allowing the train to slow down prior to reaching the crossing. In addition, the system starts the crossing warning devices by radio communications link, without depending on the traditional track circuits that were deployed appropriately for slower freight trains. It is an important requirement that warning devices start within a set time prior to the arrival of a train.

In another demonstration, the FRA has worked with the state of Illinois on the deployment of an 'arrestor net' project. In this application, possibly appropriate for very high risk crossings, the highway approach is equipped with a special net capable of safely stop-

ping even heavy highway trucks from fouling the crossings while a train is approaching.

In New York and Washington, work has proceeded on the development of a special crossing appropriate for very low density private crossings. In the Michigan Corridor as well as in other corridors, there are a number of private driveways across the tracks. One idea is to have locked gates where individuals could request that the gate open, and for which the control system would automatically determine if any trains were in the area, and open the gate, if appropriate.

Finally, the FRA has been working with Florida to develop a low cost bridge for low traffic density crossings where the local traffic patterns could allow reduced clearances. No site has yet been identified to deploy this technology.

In a related area, the FRA has developed a methodology for assessing the relative risk of various crossings in a corridor and is currently developing data on the effectiveness of new warning devices such as four quadrant gates and median barriers. These are important in assessing the actual risk posed by a change in operating frequencies and speeds. In addition, the FRA is pursuing systems that could improve the reliability of crossing systems and reduce the cost of introducing even simple active warning devices. Likewise, the FRA is studying the possible implications of traffic patterns and vehicle types on the estimates of risk. Here the implications of high traffic counts or concentrations of heavy trucks during a few periods during the day could reduce the average risk, if there were no planned trains during these periods. Conversely, if day averages are used, risks may be underestimated when high traffic counts and high train traffic coincide, such as near rush hour.

## NON-ELECTRIC LOCOMOTIVES

---

High-speed passenger rail initiatives are being considered in many corridors around the country. Most of these are not currently electrified and do not anticipate traffic densities sufficiently large to justify the capital expense of an electrification system. In order to attract ridership, these proposed services must offer competitive trip times and ticket prices. In many of these corridors the target maximum operating speed needs to be increased to between 125 and 150 mph. In addition, acceleration capabilities similar to the performance achieved with electrified trains is required to maintain high average speeds after slowing down for curves or station stops.

Almost as important as rated speed and acceleration capability, is axle load. High-speed trains must have low axle loads to reduce the damage done to the track structure at high speed. The locomotive must also be lightweight to reduce the track forces and to reduce the power requirements needed to accelerate after station stops or small radius curves. Here the goal is to limit the axle load to less than 25 tons. A typical freight locomotive has an axle load of 33 tons or more.

At the present time there are few non-electric locomotive alternatives to providing power for high-speed trains. The most common practice in the U.S. has been to take a basic locomotive designed for freight operations and to change some of the attributes such as the gearing, power conditioning and in some cases the power console. Examples of these are the P-40, P-42, F-59, and the older F-40. These locomotives have an axle load of approximately 33 tons and top speeds around 100 to 110 mph. These are all large displacement diesel engine powered locomotives that can be purchased and operated at very low cost. Nevertheless, their dynamic performance at increasing speeds has often been a limiting factor when pulling advanced tilting passenger equipment. These locomotives also have a large cross-sectional area compared to high-speed electric locomotives, greatly increasing

the aerodynamic drag further and limiting their effective top speed.

### Gas Turbine Engines

An alternative to large displacement diesel engines is a gas turbine. The first versions of the Train à Grande Vitesse, the French TGV trains, were powered with gas turbines. Several gas turbine trainsets have been used in the U.S. since the late 60's. The Rohr Turbo Liner (RTL) trains operating on the Empire Corridor in New York State are powered with very small, lightweight gas turbines. The challenge has been that the gas turbines used have been seen as expensive to operate, primarily from a maintenance and fuel consumption perspective. The problems of maintenance costs may have been largely solved with the evolution of gas turbine power for military applications and non-railroad related commercial development, most notably, for marine and aviation. A remaining problem is the fuel consumption, particularly at idle, and the variation in the power duty cycle.

### Diesel Multiple-Units

The second alternative is the diesel multiple-unit which is very popular in Europe for operations up to about 100 to 125 mph. These trains essentially have no locomotive. Many of the cars in a train are equipped with diesel engines mounted below the floor of the passenger compartment. Each engine then supplies power either electrically or hydraulically to motors mounted on one or more axles of the car. A common arrangement is to have half the cars carrying engines and half the axles being powered. The primary advantage in this arrangement is that the weight of the engines is distributed throughout the train, thereby reducing the axle load. The main disadvantage is that the distributed engines are more expensive to maintain and the train arrangement makes the design of the passenger cars more difficult. There is also an issue of crash energy management that becomes important as speeds increase.

## Initiative of the Next Generation High-Speed Rail Program

The FRA has determined that none of these approaches fully satisfies the difficult demands of high-speed passenger rail operations in U.S. corridors, and it has developed an intensive program to develop a nonelectric, lightweight, high-powered locomotive. The approach is twofold: to upgrade the existing Empire Corridor turbo train fleet and to demonstrate a truly high-performance, next generation, non-electric locomotive.

### RTL Upgrade on the Empire Corridor

The most immediate impact program was the upgrade of the existing Empire Corridor RTL turbo train fleet with higher powered gas turbines while improving the dual mode operating characteristics. These trains are required to operate on third rail power while in the tunnels approaching Pennsylvania Station in New York City. The new engines should reduce the trip time between Albany and New York City to less than 2 hours. This upgrade will not, however, improve some of the acceleration limitations of these trains at low speeds, due to the hydraulic transmission, and at high speeds, due to low peak power.

### Flywheel Energy Storage Systems

In 1995, the FRA initiated two efforts to investigate the use of flywheel energy storage devices to help reduce variations in the power duty cycle of high-speed passenger locomotives and to improve the energy efficiency of the trains. The first was an effort with the University of Texas and an industry team, including Argonne National Laboratories, General Motors - ElectroMotive Division, the AAR, Allied Signal Aerospace, Allied Signal Engines, and Avcon to investigate the use of a single large flywheel in combination with a high powered gas turbine to produce a demonstration locomotive capable of performance similar to electric locomotives. The flywheel will store enough energy to nearly double the power capability of the locomotive for up to four minutes, the time required

to accelerate to 150 mph. The flywheel will then be recharged with surplus power from the turbine while the train is at cruise speed, and from regenerative braking energy available when the train is slowing down for curves or stations. Preliminary studies indicate that use of the flywheel can reduce the fuel costs by as much as 30 percent compared with a similarly performing conventional turbo train. In these studies, the gas turbine is sized at about 3 MW, the power required to pull four typical passenger coaches at speeds up to 150 mph. The locomotive would require an additional 3 MW for several minutes to accelerate from station stops and slow curves. In addition to the fuel savings, the flywheel should be less costly to maintain as compared to an additional gas turbine.

A number of important enabling technologies make flywheels a potentially viable alternative to installing twice the rated power. The first is the advancements in the design and fabrication of composite flywheels. Using multiple rings of both carbon fiber and fiberglass with modern epoxies, manufacturers can now control and effectively manage the internal stresses within the flywheel. These designs can preclude catastrophic rim failures, making the resulting designs much safer. The next important enabling technology was the maturing of magnetic bearings. These bearings are critical in providing support to the spinning structure at very high speeds with very low losses. Finally, compact, high-power alternators are required to efficiently store and extract the energy for the rotating mass. Large flywheels rotate at speeds up to 15,000 revolutions per minute (rpm) and ideally should be coupled directly to an alternator. Allied Signal has been developing just such an alternator for military applications and has now focused on the flywheel application. A very similar alternator design can be used to generate electrical power when coupled to a gas turbine which normally operates at about 15,000 rpm.

The University of Texas has built two scale model versions of the full size flywheel to investigate details of the manufacturing and assembly process, and tests have shown the design to be even more robust than analysis had predicted. The full scale, 500 to 600 megawatt/second flywheel should be completed in 1998.

The last remaining issue is the integration of the flywheel and gas turbine into a prototype lightweight locomotive with the appropriate traction motors, power conditioning equipment, power inverters, ancillary equipment, and controls. The FRA has issued a request for proposals for a locomotive manufacturer to provide this important system integration.

An alternative to the single large flywheel is being investigated by Morrison Knudsen and the University of Idaho. The idea here is to use multiple, parallel small flywheels to achieve the same energy storage and power capabilities as with the large flywheel. Small flywheel technology is being driven by military, aerospace, transit bus and automotive applications, as well as stationary backup power supply initiatives. These applications may reduce the cost of flywheels and the associated power electronics through economies of scale unlikely to affect the large flywheel designs in the near future. Small flywheels rotate at speeds

exceeding 100,000 rpm, requiring specialized motor generators that are generally integrated into the flywheel design. The key element of the parallel designs is the cost and sizing of the individual power inverters required for each flywheel, and if these systems can be effectively controlled to mimic the performance of a single large device. Two significant advantages of the multiple approach are that a single flywheel failure would not have a big effect on the system performance and that problems with gyroscopic effects could be more simply controlled.

Finally, the FRA is monitoring the performance of high-speed diesel engines for applications in diesel multiple units and as lightweight alternatives to traditional large displacement diesel engines typical of freight service. While there are no current active projects attempting to demonstrate this technology, the non-electric locomotive demonstration project is structured to allow a variety of potential power supply configurations.

## LIGHTWEIGHT BRAKE MATERIALS

---

Ideally, both the total vehicle weight and the unsprung mass should be low. The unsprung mass is the mass in contact with the rail without the benefit of a suspension system – typically the axle, wheels, and some portion of the traction motors or disk brakes. For non-powered axles, there are often as many as four cast iron disks per axle used for friction braking. High-speed trains in Europe and Japan have experimented with lower weight steel alloy disks in combination with specially manufactured friction material to achieve longer life and

better performance when compared with traditional non-asbestos organic brake pads. Newer materials including special composite material disks may provide similar exceptional performance at greatly reduced weights. The FRA has sponsored investigations into the performance of these new materials compared with existing designs and identified a number of promising friction material combinations. Key issues remaining, such as the cost of manufacturing these components, will ultimately determine their marketability.

# **PUBLISHED REPORTS**



## PUBLISHED REPORTS

---

Report Number	NTIS Number	Author	Report Title
FRA/ORD-92/01	PB92-167006	TÜV Rheinland	Safety of High Speed Magnetic Levitation Transportation Systems: High Speed Maglev Trains: German Safety Requirements RW-MSB
FRA/ORD-92/02	PB92-167014	Volpe Center	Safety of High Speed Magnetic Levitation Systems: German High Speed Maglev Train Safety Requirements: Potential for Application in the United States
FRA/ORD-92/03	PB92-224252	Canadian Institute of Guided Ground Transport: ENSCO, Inc.	High Speed Tilt Train Technology: A State-of-the-Art Survey
FRA/ORD-92/04	PB92-205335	Association of American Railroads/ Transportation Technology Center, Inc. (AAR/TTC)	Safety Aspects of New Trucks and Lightweight Cars, Car 2
FRA/ORD-92/07	PB94-162823	AAR/TTC	Field Testing of a Wayside Wheel Crack Detection System
FRA/ORD-92/08	PB93-226603	AAR/TTC	Roller Bearing Failure Mechanism Test and Wheel Anomaly Test Report
FRA/ORD-92/09.1	PB92-224666	Electric Research and Management, Inc.	Safety of High Speed Magnetic Levitation Transportation Systems: Magnetic Field Testing of TR-07 Maglev Vehicle and System Conducted August 1990. Volume 1. Analysis
FRA/ORD-92/09.2	PB92-224674	Electric Research and Management, Inc.	Safety of High Speed Magnetic Levitation Transportation Systems: Magnetic Field Testing of TR-07 Maglev Vehicle and System Conducted August 1990. Volume 2. Appendices
FRA/ORD-92/11	PB93-131316	Volpe Center	Chlorine Tank Car Puncture Resistance Evaluation

Report Number	NTIS Number	Author	Report Title
FRA/ORD-92/13	PB93-126530	Battelle: Booz, Allen & Hamilton Carnegie Mellon Research Institute	Safety of High Speed Guided Ground Transportation Systems: Shared Right-of-Way Safety Issues
FRA/ORD-92/14	PB93-105641	Federal Railroad Administration	Improving Transportation Through Railroad Research: 1988-1991
FRA/ORD-92/15	PB94-158318	AAR/TTC	Evaluation of Two Prototype Devices for Non-Destructively Measuring Stresses in Railroad Wheels
FRA/ORD-92/16	PB94-162849	AAR/TTC	Effect of Worn Components on Brake Forces in a Freight Car Rigging
FRA/ORD-92/17	PB93-175008	Illinois Institute of Technology Research Institute (IITRI)	Enginemen Stress and Fatigue: Pilot Study
FRA/ORD-92/18.1	PB93-206952	Battelle	Hazardous Materials Car Placement in a Train Consist (Volume 1 – Review and Analysis)
FRA/ORD-92/18.2	PB93-206960	Battelle	Hazardous Materials Car Placement in a Train Consist (Volume 2 – Appendices)
FRA/ORD-92/19	PB92-219708	AAR/TTC	Peacekeeper Rail Garrison Test of Launch Control Car EMS-2
FRA/ORD-92/20	PB92-222835	AAR/TTC	Peacekeeper Rail Garrison Test of Missile Launch Car EMS-1
FRA/ORD-92/21	PB92-219716	AAR/TTC	Peacekeeper Rail Garrison Test of Engineering Model Maintenance Car
FRA/ORD-92/22	PB92-224450	AAR/TTC	Peacekeeper Rail Garrison Test of Engineering Model Fuel Car
FRA/ORD-92/23	PB92-228378	AAR/TTC	Peacekeeper Rail Garrison Train Dynamics Testing and Train Mobility Evaluation
FRA/ORD-92/24	PB92-219724	AAR/TTC	Peacekeeper Rail Garrison Vehicle Characterization Test of Triplet Cars, ATSC 9004 and 90006

Report Number	NTIS Number	Author	Report Title
FRA/ORD-92/25	PB92-224427	AAR/TTC	Peacekeeper Rail Garrison Triplet Cars Track Worthiness Test
FRA/NMI-92/26	PB-93-154888		Verification Methodology for Fault-Tolerant, Fail-Safe Computers Applied to Maglev Control Computer Systems
FRA/ORD-92/27	PB93-223501	AAR/TTC	Field Product Removal Methods for Tank Cars
FRA/ORD-92/28	PB93-134039	AAR/TTC	Controlled Tank Car Impact Tests
FRA/ORD-92/29	PB93-223493	AAR/TTC	Aluminum/Cold Temperature Tank Car Puncture Resistance Tests: Data Report
FRA/ORD-92/32	PB93-132546	IITRI	Advanced Train Control System Evaluation
FRA/ORD-92/34	PB93-223477	Technology & Management Systems, Inc.	Hazardous Material Transportation in Tank Cars – Analysis of Risks, Part I
FRA/ORD-93/01.1	PB93-219434	Electric Research and Management, Inc.	Safety of High Speed Guided Ground Transportation Systems: Magnetic and Electric Field Testing of the Amtrak Northeast Corridor and New Jersey Transit/North Jersey Coast Line Rail Systems, Volume 1. Analysis
FRA/ORD-93/01.2	PB93-219442	Electric Research and Management, Inc.	Safety of High Speed Guided Ground Transportation Systems: Magnetic and Electric Field Testing of the Amtrak Northeast Corridor and New Jersey Transit/North Jersey Coast Line Rail Systems. Volume 2. Appendices
FRA/ORD-93/02.1	PB93-205268	Arthur D. Little, Inc.	Safety of High Speed Guided Ground Transportation Systems: Collision Avoidance and Accident Survivability. Volume 1. Collision Threat
FRA/ORD-93/02.2	PB93-205276	Arthur D. Little, Inc. Parsons Brinckerhoff Quade & Douglas	Safety of High Speed Guided Ground Transportation Systems: Collision Avoidance and Accident Survivability. Volume 2. Collision Avoidance

Report Number	NTIS Number	Author	Report Title
FRA/ORD-93/02.3	PB93-205284	Arthur D. Little, Inc. Calspan Corporation	Safety of High Speed Guided Ground Transportation Systems: Collision Avoidance and Accident Survivability. Volume 3. Accident Survivability
FRA/ORD-93/02.4	PB93-205292	Arthur D. Little, Inc.	Safety of High Speed Guided Ground Transportation Systems: Collision Avoidance and Accident Survivability. Volume 4. Proposed Specifications
FRA/ORD-93/03.1	PB93-223071	Electric Research and Management, Inc.	Safety of High Speed Guided Ground Transportation Systems: Magnetic and Electric Field Testing of the French Train á Grande Vitesse (TGV) Rail Systems. Volume 1. Analysis
FRA-ORD-93/03.2	PB93-223089	Electric Research and Management, Inc.	Safety of High Speed Guided Ground Transportation Systems: Magnetic and Electric Field Testing of the French Train á Grande Vitesse (TGV) Rail Systems. Volume 2. Appendices
FRA/ORD-93/04.1	PB94-102472	Electric Research and Management, Inc.	Safety of High Speed Guided Ground Transportation Systems: Magnetic and Electric Field Testing of the Washington Metropolitan Area Transit Authority Metrorail System. Volume 1. Analysis
FRA/ORD-93/04.2	PB94-102480	Electric Research and Management, Inc.	Safety of High Speed Guided Ground Transportation Systems: Magnetic and Electric Field Testing of the Washington Metropolitan Area Transit Authority Metrorail System. Volume 2. Appendices
FRA/ORD-93/05.1	PB93-227619	Electric Research and Management, Inc.	Safety of High Speed Guided Ground Transportation Systems: Magnetic and Electric Field Testing of the Massachusetts Bay Transportation Authority (MBTA) Urban Transit System. Volume 1. Analysis
FRA/ORD-93/05.2	PB93-227627	Electric Research and Management, Inc.	Safety of High Speed Guided Ground Transportation Systems: Magnetic Electric Field Testing of the Massachusetts Bay Transportation Authority (MBTA) Urban Transit System. Volume 2. Appendices

Report Number	NTIS Number	Author	Report Title
FRA/ORD-93/07	PB94-103397	Electric Research and Management, Inc.	Safety of High Speed Guided Ground Transportation Systems: Comparison of Magnetic and Electric Fields of Conventional and Advanced Electrified Transportation Systems
FRA/ORD-93/08	PB93-217339	Thomas K. Dyer, Inc.;Foster-Miller, Inc.	Safety of Vital Control and Communication Systems in Guided Ground Transportation: Analysis of Railroad Signaling System: Microprocessor Interlocking
FRA/ORD-93/09	PB94-173697	AAR/TTC	Hazardous Materials Emergency Response Plan Guidance Document For Railroads
FRA/ORD-93/10	PB93-223436	AAR/TTC	Tank Car Fatigue Crack Growth
FRA/ORD-93/12	PB93-208544	AAR/TTC	Evaluation of Rail Rollover Derailment Study
FRA/ORD-93/13	PB93-194645	AAR/TTC	X2000 U.S. Demonstration Vehicle Dynamics Trials Preliminary Test Report
FRA/ORD-93/15	PB93-228104	Volpe Center	Evaluation of Immediate Actions Taken to Deal with Cracking Problems Observed in Wheels of Rail Commuter Cars
FRA/ORD-93/17	PB94-108248	Volpe Center	Finite Element Models, Validation, and Results for Wheel Temperature and Elastic Thermal Stress Distributions
FRA/ORD-93/18	PB94-109469	Volpe Center	Stress Reconstruction Analysis of Wheel Saw Cut Tests and Evaluation of Reconstruction Procedure
FRA/ORD-93/21	PB97-188148	Arthur D. Little, Inc.; Parsons Brinckerhoff Quade & Douglas	Safety of High Speed Magnetic Levitation Transportation Systems: Comparison of U.S. and Foreign Safety Requirements for Application to U.S. Maglev Systems
FRA/ORD-93/23	PB94-152006	National Institute of Standards and Technology(NIST)	Fire Safety of Passenger Trains: A Review of U.S. and Foreign Approaches

Report Number	NTIS Number	Author	Report Title
FRA/ORD-93/24	PB94-154721	Volpe Center	Recommended Emergency Preparedness Guidelines for Passenger Trains
FRA/ORD-93/25	PB94-139656	Volpe Center	Safety of Highway Railroad Grade Crossings: Study of the Acoustic Characteristics of Railroad Horn Systems
FRA/ORD-93/26	PB94-154648	Foster-Miller, Inc.	Parametric Analysis and Safety Concepts of CWR Track Buckling
FRA/ORD-93/27	PB94-117819	U.S. Environmental Protection Agency	Safety of High Speed Guided Ground Transportation Systems: Review of Existing EMF Guidelines, Standards and Regulations
FRA/ORD-93/28	PB94-152402	U.S. Environmental Protection Agency	Safety of High Speed Guided Ground Transportation Systems: EMF Exposure Environments Summary Report
FRA/ORD-93/29	PB94-129780	U.S. Environmental Protection Agency	Safety of High Speed Guided Ground Transportation Systems: Broadband Magnetic Fields: Their Possible Role In EMF-Associated Bioeffects
FRA/ORD-93/30	PB94-118593	Argonne National Laboratory	Safety of High Speed Guided Ground Transportation Systems: The Biological Effects of Maglev Magnetic Field Exposures
FRA/ORD-93/31	PB94-121217	Information Ventures, Inc.	Safety of High Speed Guided Ground Transportation Systems: Potential Health Effects of Low Frequency Electromagnetic Fields Due to Maglev and Other Electric Rail Systems
FRA/ORD-93/32	PB94-128220	Information Ventures, Inc.	Safety of High Speed Guided Ground Transportation Systems: An Overview Of Biological Effects and Mechanisms Relevant to EMF Exposures from Mass Transit and Electric Rail Systems
FRA/ORD-93/33	PB93-236065	Arthur D. Little, Inc.	The Development and Application of Rail Defect Fracture Models to Assess Remedial Actions

Report Number	NTIS Number	Author	Report Title
FRA/RDV-93-01-A	PB94-110210	FRA/Volpe Center	Northeast Corridor Improvement Project Electrification – New Haven, CT to Boston, MA: Draft Environmental Impact Statement
FRA-RDV-93-01-B	PB94-122017	FRA/Volpe Center	Northeast Corridor Improvement Project Electrification – New Haven, CT to Boston, MA: Draft Environmental Impact Statement/ Report. Volume 2. Land Use and Regulated Areas
FRA-RDV-93-01-C	PB94-111838	FRA/Volpe Center	Northeast Corridor Improvement Project Electrification – New Haven, CT to Boston, MA: Draft Environmental Impact Statement/ Report. Volume 3. Technical Studies
FRA/NMI-94/1	PB94-204708	Volpe Center	Study to Establish Ride Comfort Criteria for High Speed Magnetically Levitated Transportation Systems
FRA/ORD-94/01	PB96-204227	Massachusetts Institute of Technology (MIT)	Thermomechanical Testing and Microstructural Development of Class L Steel Wheel Alloy
FRA/ORD-94/02	PB94-129558	State University of New York at Stony Brook, NY	Experimental Study of Residual Stresses in Rail by Moire Interferometry
FRA/ORD-94/10	PB96-131354	Foster-Miller, Inc.	Safety of High Speed Magnetic Levitation Systems: Thermal Effects and Related Safety Issues of Typical Maglev Steel Guideways
FRA/ORD-94/11	PB94-191863	AAR/TTC	Side Bearing Clearance Testing Research
FRA/ORD-94/12	PB94-173689	ENSCO, Inc.	Experimental Residual Stress Measurement of New and Used Commuter Rail Wheels
FRA/ORD-94/15	PB94-156916	ENSCO, Inc.	X2000 U.S. Demonstration Vehicle Dynamics Test (Final Test Report)
FRA/ORD-94/16	PB96-144357	Volpe Center	Study of Braking Operations Using a Locomotive Simulator

Report Number	NTIS Number	Author	Report Title
FRA/ORD-94/20	PB94-206216	ENSCO, Inc.	Overview of Railroad Bridges and Assessment of Methods to Monitor Railroad Bridge Integrity
FRA/ORD-94/22.1	PB94-206141	AAR/TTC	The Northeast Corridor Transportation Plan (July 1994) (New York City to Boston), Volume I – Report to Congress
FRA/ORD-94/22.2	PB94-204153	AAR/TTC	The Northeast Corridor Transportation Plan (July 1994) (New York City to Boston), Volume II – Appendices A Through O
FRA/ORD-94/24	PB95-217857	Massachusetts Institute of Technology (MIT)	Safety of High Speed Guided Ground Transportation Systems – Human Factors, Phase I: Function Analyses and Theoretical Considerations
FRA/ORD-94/25	PB95-193041	ENSCO, Inc.	ICE/U.S. Demo Vehicle Dynamics Tests (Test Report)
FRA/RDV-94-01-A	PB95-179990	FRA/Volpe Center	Northeast Corridor Improvement Project Electrification – New Haven, CT to Boston, MA: Final Environmental Impact and Statement/Report and 4(f) Statement. Volume 1
FRA-RDV-94-01-B	PB95-174447	FRA/Volpe Center	Northeast Corridor Improvement Project Electrification – New Haven, CT to Boston, MA: Final Environmental Statement/Report: Volume 2. Technical Studies
FRA-RDV-94-01-C	PB95-179982	FRA/Volpe Center	Northeast Corridor Improvement Project Electrification – New Haven, CT to Boston, MA: Final Environmental Impact Statement/Report: Volume 3. Response
FRA-RDV-94-01-D	PB95-182002	FRA/Volpe Center	Northeast Corridor Improvement Project Electrification – New Haven, CT to Boston, MA: Final Environmental Impact Statement/Report: Volume 4. Comment
FRA-RDV-94-01-E	PB95-189551	FRA/Volpe Center	Northeast Corridor Improvement Project Electrification – New Haven, CT to Boston, MA: Final Environmental Impact Report: Supplement

Report Number	NTIS Number	Author	Report Title
FRA-RDV-94-01-G	PB96-176284	FRA	Northeast Corridor Improvement Project Electrification – New Haven, CT to Boston, MA: Record of Decision: Final Environmental Impact Statement
FRA-RDV-94-01-H	PB96-176292	FRA/Volpe Center	Northeast Corridor Improvement Project Electrification – New Haven, CT to Boston, MA: Appendix to the Final Environmental Impact Report Supplement
FRA/ORD-95/04	PB96-107065	Parsons Brinckerhoff Quade and Douglas	Safety of High Speed Guided Ground Transportation Systems: Intrusion Barrier Design Study
FRA/ORD-95/05	PB95-251781	Arthur D. Little, Inc./ Parsons Brinckerhoff Quade and Douglas	High Speed Passenger Trains in Freight Railroad Corridors: Operations and Safety Considerations
FRA/ORD-95/08	PB95-271722	Arthur D. Little, Inc.	Locomotive Crashworthiness Research: Executive Summary
FRA/ORD-95/08.1	PB95-271730	Arthur D. Little, Inc.	Locomotive Crashworthiness Research: Volume 1. Model Development and Validation
FRA/ORD-95/08.2	PB95-271748	Arthur D. Little, Inc.	Locomotive Crashworthiness Research: Volume 2. Design Concept Generation and Evaluation
FRA/ORD-95/08.3	PB95-271755	Arthur D. Little, Inc.	Locomotive Crashworthiness Research: Volume 3. Review and Discussion of Freight Locomotive Crashworthiness Concepts
FRA/ORD-95/08.4	PB95-271763	Arthur D. Little, Inc.	Locomotive Crashworthiness Research: Volume 4. Additional Freight Locomotive Calculations
FRA/ORD-95/08.5	PB97-134837	Arthur D. Little, Inc.	Locomotive Crashworthiness Research: Volume 5: Cab Car Crashworthiness Report

Report Number	NTIS Number	Author	Report Title
FRA/ORD-95/09.1	PB96-118021	Battelle	Safety of High Speed Ground Transportation Systems: Safety of Advanced Braking Concepts for High Speed Ground Transportation Systems
FRA/ORD-95/10.1	PB96-109772	Battelle	Safety of High Speed Ground Transportation Systems: Analytical Methodology for Safety Validation of Computer Controlled Subsystems; Vol 1. State-of-the-Art and Assessment of Safety Verification/Validation Methodologies
FRA/ORD-95/10.2	PB96-109780	Battelle	Safety of High Speed Ground Transportation Systems: Analytical Methodology for Safety Validation of Computer Controlled Subsystems; Vol 2. Development of a Safety Validation Methodology
FRA/ORD-95/13	PB96-183504	Volpe Center	Safety of Highway-Railroad Grade Crossings: Use of Auxiliary External Alerting Devices to Improve Locomotive Conspicuity
FRA/ORD-95/14.1	PB96-183264	Volpe Center	Safety of Highway-Railroad Grade Crossings: Research Needs Workshop. Volume 1
FRA/ORD-95/14.2	PB96-183256	Volpe Center	Safety of Highway-Railroad Grade Crossings: Research Needs Workshop. Volume 2. Appendices
FRA/ORD-96/01	PB97-105142	Arthur D. Little, Inc./Parsons Brinckerhof Quade and Douglas	Design Data on Suspension Systems of Selected Rail Passenger Cars
FRA/ORD-96/02	PB96-204235	Massachusetts Institute of Technology (MIT)	Estimation of Actual Residual Stresses Due to Braking and Contact Loading of Rail Vehicle Wheels
FRA/ORD-96/03	PB96-172788	Foster-Miller, Inc.	Safety of High Speed Ground Transportation Systems: Track Lateral Shift: State-of-the-Art Review
FRA/ORD-96/04	PB96-202023	Volpe Center	Procedure to Establish Inspection Intervals of Regularly Maintained In-Service units Subject to Failure Investigation of the Effects of Braking
FRA/ORD-96/06	PB97-179261	Volpe Center	

Report Number	NTIS Number	Author	Report Title
			System Configuration on Thermal Input to Commuter Car Rails
FRA/ORD-96/08	PB97-137343	Volpe Center	Crashworthiness Testing of Amtrak's Traditional Coach Seat
FRA/ORD-96/09	PB97-140701	Human-Machine Systems Laboratory: MIT	Safety of High Speed Guided Ground Transportation Systems, Human Factors Phase II: Design and Evaluation of Decision Aids for Control of High-Speed Trains: Experiments and Model
FRA/ORD-97/01	PB98-102742	Volpe Center	Investigation of CWR Longitudinal Restraint Behavior in Winter Rail Break and Summer Destressing Operations
FRA/ORD-97/02	PB97-194724	Volpe Center	Analyses of Track Shift under High Speed Vehicle-Track Interaction
FRA/ORD-97/06	PB99-140121	Concurrent Technologies Corporation	Experimental Determination of Release Fields in Cut Railroad Car Wheels
FRA/ORD-97/08	PB98-136385	Volpe Center	Rail Vehicle Crashworthiness Symposium – June 24-26, 1996
FRA/ORD-97/09		FRA/ITRI	Effects of Work Schedule on Train Handling Performance and Sleep of Locomotive Engineers: A Simulator Study
FRA/ORD-97/10	PB98-134406	Volpe Center	Crashworthiness of Passenger Trains
FRA/ORD-97/11	PB98-136377	Volpe Center	Intelligent Transportation Systems and Their Implications for Railroads, June 4-5, 1997
Meeting Proceedings		Volpe Center	GPS and ITS Application to Railroad Operations, November 14&15, 1996



# PLANNED REPORTS



## PLANNED REPORTS

---

<u>Author</u>	<u>Report Title</u>
TTC	Prototype VPAS Testing
Technology & Management Systems, Inc.	Analysis of Rail Chill Effect
Volpe Center	Safety of High Speed Ground Transportation Systems, Parametric Analysis and Safety Concepts for Track Lateral Shift
Volpe Center	Safety of Highway-Railroad Grade Crossings: Field Evaluation of a Wayside Horn
Volpe Center	Propagation Analysis of Transverse Defects Originating at the Lower Gage Corner of Rail
Volpe Center	Estimation of Rail Wear Limits Based on Rail Strength Investigations
-----	Vehicle Suspension Systems for High- Speed Guided Transportation Systems
Battelle	Safety of Highway-Railroad Grade Crossings. Volume I: Signaling/Control Technologies for High-Speed Rail Transportation Corridors

Author	Report Title
Battelle	Safety of Highway-Railroad Grade Crossings. Volume II: Obstruction Detection Technologies for High-Speed Rail Transportation Corridors
Battelle	Safety of Highway-Railroad Grade Crossings. Volume III: Warning Device and Barrier System Technologies for High-Speed Rail Transportation Corridors
Massachusetts Institute of Technology (MIT)	Safety of High Speed Ground Transportation Systems, Human Factors, Phase III: Effects of Control Automation on Operator Performance
Metallurgical Consulting	Considerations for the Development of Alloys Suitable for Use in In-Line Hardening of Rails, Wheels and Tank Car Plate Having Lower Bainite Microstructures
National Institute of Standards and Technology	Fire Safety of Passenger Trains - Phase I: Material Evaluation in the Cone Calorimeter
National Institute of Standards and Technology	Fire Safety of Passenger Trains - Phase II: Fire Hazard Analysis Report
National Institute of Standards and Technology	Fire Safety of Passenger Trains - Phase III: Real-Scale Testing of Assemblies
Technology and Management Systems	Controlled Quenching of Flat Rolled Steel Plate to Produce Lower Bainite
Volpe Center	Assessment of Highway-Railroad Grade Crossing Risks: Empire Corridor Case Study

Author	Report Title
Volpe Center	Assessment of Potential Aerodynamic Effects on Personnel and Equipment in Proximity to High-Speed Rail Operations
Volpe Center	Compliance with Railroad Operating Rules and Corporate Culture Influences: Results of a Focus Group and Structured Interviews
Volpe Center	Estimation of Residual Stresses in Railroad Commuter Car Wheels Following Manufacture
Volpe Center	Human Factors Guidelines for the Evaluation of the Locomotive Cab
Volpe Center	Passenger Acceptance of Alignments with Frequent Curves in Maglev or Other Very High-Speed Ground Systems
Volpe Center	Safety of Highway-Railroad Grade Crossings: Freight Car Reflectorization
Volpe Center	Safety of Highway-Railroad Grade Crossings: Illumination Guidelines
Volpe Center	Safety of Highway-Railroad Grade Crossings: Railroad Horn Systems Research
Volpe Center	Vehicle Proximity Alerting Systems Prototype Research
Foster-Miller, Inc.	Shorter-than-24-hour Work/Rest Cycles in the Railroad Industry
Foster-Miller, Inc.	Railroad Worker Safety in Yards and Terminals

Author	Report Title
Foster-Miller, Inc.	Railroad Dispatcher Workload, Stress, and Fatigue

# ACRONYMS



# ACRONYMS

---

AAR	Association of American Railroads
AAR/TTC	Organization responsible for operating TTC for the FRA, 1992-1997
AATC	Advanced Automatic Train Control
ACSES	Advanced Civil Speed Enforcement System
AREA	American Railway Engineering Association
AREMA	American Railway Engineering and Maintenance-of-Way Association
ARES	Advanced Railroad Electronics System
ATCS	Advanced Train Control System
ATO	Automatic Train Operating (System)
CBTC	Communications-Based Train Control
CRAM	Corridor Risk Assessment Model
CTC	Centralized Train Control
CWR	Continuous Welded Rail
DGPS	Differential Global Positioning System
DMU	Diesel Multiple Unit
DOT	Department of Transportation
DTA	Damage-Tolerance Analysis
ECPBP	Electronically Controlled Pneumatic Brake Program
ELF	Extremely Low Frequency
EMC	Electromagnetic Compatibility
EMF	Electromagnetic Fields
EMI	Electromagnetic Interference
EMR	Electromagnetic Radiation
EPLRS	Enhanced Position Location and Reporting System
ERTMS	European Radio and Traffic Management System
ETCS	European Train Control System
FAST	Facility for Accelerated Service Testing
FCP	Fatigue Countermeasures Programs
FDOT/FOX	Florida Department of Transportation/Florida Overland Express
FEEST	Freight Equipment and Environmental Sample Test
FHWA	Federal Highway Administration

FRA	Federal Railroad Administration
GIS	Geographic Information System
GPS	Global Positioning System
GRMS	Gage Restraint Measurement System
GWEN	Ground Wave Emergency Network
HAL	Heavy Axle Load
HAZMAT	Hazardous Materials
HRR	Heat Release Rate
HSGT	High-Speed Ground Transportation
HSR	High-Speed Rail
HTSC	High-Temperature Superconductor
ICS	Intermodal Control System
IDEA	Innovations Deserving Exploratory Analysis (TRB)
IITRI	Illinois Institute of Technology Research Institute
ISTEA	Intermodal Surface Transportation Efficiency Act
ITCS	Incremental Train Control System
ITS	Intelligent Transportation System
LOS	Loss of Shunt
L/V RATIO	Lateral to Vertical Load Ratio
NDE	Nondestructive Evaluation
NDI	Nondestructive Inspection
NDT	Nondestructive Technique
NEC	Northeast Corridor
NECIP	Northeast Corridor Improvement Project
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
NTPC	National Traction Power Committee
NTSB	National Transportation Safety Board
NUCARS	New and Untried Cars Analytical Regime Simulations
PRC	Peer Review Committee
PTC	Positive Train Control
PTS	Positive Train Separation
RAC	Railway Association of Canada
RALES	Research and Locomotive Evaluator/Simulator
RFR	Radio Frequency Radiation

ROW	Right-of-Way
RPI	Railway Progress Institute
RSAC	Railroad Safety Advisory Committee
RSERA	Rail Safety Enforcement and Review Act
RTL	Rohr Turbo Liner
SBIR	Small Business Innovative Research (Program)
SCD	System Concept Definition
SPL	Sound Pressure Level
STPT	Single Tie Push Test
TGV	Train á Grande Vitesse
TLV	Track Loading Vehicle
TMCP	Thermo-Mechanically Controlled Processing
TRB	Transportation Research Board
TTC	Transportation Technology Center
TTCI	Transportation Technology Center, Inc.-formed as a subsidiary of AAR January 1, 1998
VAB	Vehicle Arresting Barrier System
VPAS	Vehicle Proximity Alert System
V/TIP	Vehicle/Track Interaction Program
VTU	Vibration Test Unit
WIU	Wayside Interface Unit
WLAN	Wayside Local Area Network









- ◀ Human Factors
- ◀ Rolling Stock
- ◀ Track Systems and Structures
- ◀ Vehicle/Track Interaction
- ◀ Intelligent Track/Train Systems
- ◀ Highway-Rail Grade Crossing Safety
- ◀ Hazardous Material
- ◀ Train Occupant Safety
- ◀ High-Speed Rail Safety Assurance Program
- ◀ Research and Development Facilities and Test Equipment
- ◀ Next Generation High-Speed Rail
- ◀ Published Reports
- ◀ Planned Reports
- ◀ Acronyms

- ◀ Human Factors
- ◀ Rolling Stock
- ◀ Track Systems and Structures
- ◀ Vehicle/Track Interaction
- ◀ Intelligent Track/Train Systems
- ◀ Highway-Rail Grade Crossing Safety
- ◀ Hazardous Material
- ◀ Train Occupant Safety
- ◀ High-Speed Rail Safety Assurance Program
- ◀ Research and Development Facilities and Test Equipment
- ◀ Next Generation High-Speed Rail
- ◀ Published Reports
- ◀ Planned Reports
- ◀ Acronyms